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Physics simulations and their influence on conceptual change in students

by

Kenneth Marcellus

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A DEDICATION

To my wife Sandra and my two children, Rebekah and Jacob, for their patience while I pursued this thesis. Without their support, I would not have been able to devote all of the hours I did to this degree.

ABSTRACT

This research was designed to determine what conceptual changes occur when students use computer simulations, and whether simulations with characteristics defined as engaging by Adams et al. (2008a; 2008b), Granlund, Berglund, and Eriksson (2000), Kali and Linn (2008), Kim, Yoon, Whang, Tversky, and Morrison (2007), Lowe (2004), Malone (1981), and Wishart (1990), seem to promote conceptual change. Six grade-ten students worked with three projectile-motion simulations in various orders. Students drew pre- and post-treatment concept maps, their interactions with the simulations were videotaped, and they were interviewed. The results show that the students did experience conceptual change, but the changes were mostly within existing cognitive frameworks with few higher-order connections made. As well, the simulation that engaged the students the most promoted the least conceptual change, and vice versa. These findings support recommendations made in earlier literature that raise awareness of simulation features that tend to distract students from learning goals.

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CHAPTER 1: INTRODUCTION

1.1 Background

This research emerges from three current movements in western education systems. One is a change in the role of the teacher from being a presenter of knowledge to a facilitator of conceptual change for students. Another is the growing desire amongst educators for students to develop what are being called 21st century skills. The final movement is the interest of teachers to integrate technologies into their lessons and classrooms. In this research, I have investigated one technology that could be used in high school science classrooms – web simulations – and their effect on conceptual change in students. In this paper, I also discuss the potential for these technologies to assist students to develop 21st century skills.

1.1.1 Changing Role of the Teacher

Education systems are highly inertial with respect to change, a point that is echoed in a report by the National Council for Accreditation of Teacher Education (1997):

> For teachers and students alike, learning at all levels of education has been primarily a process of reading what experts have written, discussing what has been read, and listening to teachers explain or expand upon textbooks. In most cases, schooling has become a process for understanding, retaining, and reporting what is found on the printed page (p. 9).

That same report goes on to discuss the shift from traditional learning methods to ones that are student-centred, and where the teacher acts more as a facilitator that offers assistance, guidance, and advice to students who become much more active in their learning, rather than passive. That report states the following:

> Once, a teacher who was well prepared in the subject she taught, experienced in the design of interesting classroom activities, and on top of information conveyed by the textbook, could contemplate a long career in teaching without having to change her style or practice very much. Those days are over (p. 11).

Traditional teaching practices in science classrooms have been exemplified by instructional activities such as the following: giving lecture notes, providing answers to questions, reporting desired results for experiments, demonstrating and modelling techniques, and presenting scientific terms and concepts outside of contexts (Novak & Gowin, 1984; Odom, Stoddard, & LaNasa, 2007). These practices promote rote learning and do not allow for deep, conceptual understanding (Odom, et al., 2007), and are very teacher-centred, such that the lesson content, learner attention, wall decorations, and even the physical arrangement of the learning area–typically desks in rows facing the teacher–are "conducive to performance and…the teacher's role is just that; to perform, to modulate their voice, to display their knowledge, to exaggerate a point, to gesture, and, inevitably, to engage a class as an actor does an audience" (Watkins, 2007, p. 769). These activities within a teacher-centred learning environment assume that the knowledge and skills of the teacher need simply be transmitted to students.

The need to change the role of the teacher away from being the focus of attention is expressed well by Novak and Gowin (1984):

> For almost a century, students of education have suffered under the yoke of the behavioural psychologist, who see learning as synonymous with a

> change in behaviour. We reject this view, and observe instead that learning by humans leads to a change in the meaning of experience (p. xi).

Novak and Gowin (1984) go on to say that, “Teachers have been working very hard to achieve what is both impractical and burdensome, and therefore costly: We have expected them to *cause* learning in students, when of course learning must be *caused by* the learner”, with the goal of teaching being the, “achievement of shared meaning” (p. xii).

The Cisco white paper (2008) suggests that the primary changes in pedagogy should be: a shift to learner-centred instruction; the use of a wider variety of pedagogical strategies; the use of inter-disciplinary and project-based learning; and authenticity in lessons (p. 11). McCoog (2008) proposes that teachers should not deliver content, but rather engage students with technology in order to individually tailor their instruction, which is also voiced by White-Clark, DiCarlo, and Gilchriest (2008). As well, teachers should be allowed to give students pacing options, allowing those students who can finish material quicker to do so. In order to bring about real learning of 21st century skills, educators must make the wholesale shift from traditional, objectivist, didactic teaching methods to embracing those methods based on constructivist learning theory (Jonassen, Peck, & Wilson, 1999; Kent & McNergney, 1999; Knapp & Glenn, 1996). However, this shift should be done with care. While teachers are now being encouraged to adopt more student-centred teaching practices, the support for this shift needs more investigation because current research is somewhat mixed. Giles, Ryan, Belliveau, De Freitas, and Casey (2006) suggest a balance of student-centred and teacher-centred approaches may be appropriate, given the fact that their study found that higher achieving students benefited most from student-centred approaches, lower achieving students from teacher-centred approaches, and middle-achieving students equally well from both approaches.

1.1.2 21st Century Skills

Society is demanding different types of graduates than it did in years past. While general knowledge and a good work ethic were sufficient to allow a graduate to find work in the past, this is no longer the case. In the latter portion of the 20th century, schools were being tasked with teaching students technology skills, mainly those associated with computers, and with imparting skills to students that they could use to conduct their own learning throughout their lives. Now, information management is becoming just as crucial as a job requirement (Breivik, 2005), and educators are being asked to bridge the gap again.

Several people and organizations are striving to define what 21st century skills are (Breivik, 2005; Cisco Systems Inc., 2008; McCoog, 2008), and some commonalities are emerging:

- critical thinking
- problem solving
- collaboration/communication
- information management
- digital literacy (skills using or understanding a wide array of technologies)

At the very least, the simulations used in this research should allow students to work toward developing these skills. The students will be investigating changes in parameters of their choosing and evaluating the results (critical thinking, problem solving), they will be keeping track of what they learn on their concept maps and with their calculators and scrap paper (information management), and they will likely be experiencing a different use of a common technology (digital literacy). If students were allowed to work together, the skills of collaboration and communication could also be utilised.

While these common 21st century skills may not seem completely new – all of us were required to think critically, solve problems, work in teams, and manage information in past generations in schools – what is important to notice is that these skills have taken on a new focus in society. Schools are expected to integrate these skills with traditional content so that students leave school able to handle a society that focuses more on facility with these skills, rather than content knowledge, in everyday life. One of the tools that teachers may be able to use to develop some of these 21st century skills is the educational simulation, which is a software solution that allows students to experience and interact with a phenomenon on a computer. If this technology is used judiciously by teachers, it may be able to promote all of the 21st century skills listed in this section.

1.1.3 Introduction to Educational Simulations and Their Possible Role

The generation of students that are in North American schools right now have not known a society without computers or the worldwide web. The most innovative educators are finding ways to incorporate these technologies into their instruction and to introduce students to technologies which they can interact with intuitively, which "offers further opportunities for expressing, evaluating and revising their developing ideas as they visualise the consequences of their own reasoning" (Hennessy, et al., 2007, p. 138). Hennessy et al. (2007) specifically investigated at the benefits of students using simulations in science classrooms. Simulations allow students to investigate highly exploratory ideas while yielding data that does not require the level of open interpretation and *cleaning*, which is the handling of problematic data or outliers, that data from real investigations tend to require.

Corder (2005a) lists eight benefits of students using simulations in science classrooms:

- students can repeat a demonstration or laboratory that they have done in class as many times as they would like,
- as a demonstration tool, an instructor can make a simulation visible to every student in any room, even large lecture theatres, using projection hardware which might not be possible with equipment-based demonstrations,
- abstract phenomena are difficult to demonstrate with traditional means, but not so with simulations,
- simulations provide a safe medium to explore in,
- simulations are less expensive because the hardware used is generic to all simulations and is not consumed during trials,
- when used as exploratory assignments, students tended to use higher order cognitive skills with simulations than when they completed regular assignments,
- students who are curious can benefit from venturing outside of the parameters that the teacher might normally consider as part of the assignment, and
- reviewing for examinations is deeper and more meaningful. (p. 48)

In a later article, Corder (2005b) published a list of six disadvantages of students using simulations in science classrooms, mainly technical in nature:

- some students do not have internet access or a computer at home,

- a simulation or its URL may be temporarily unavailable or it may be removed permanently,
- bandwidth may be too limited for the use of a simulation at a given time or location,
- temporary computer or network problems can postpone the use of a simulation,
- additional software may be needed for a simulation to function properly, and this might cause access and/or compatibility issues, and
- too much reliance on simulations may shield students from a necessary exposure to authentic hands-on science investigations, and "teachers must be sure that [simulations] are not used in exclusion of other activities" (p. 47).

Corder's (2005b) list of disadvantages is mostly technical. Indeed, five of the six are simply technical issues, while only one deals with cognitive development. The last disadvantage listed is echoed by Hennessy et al. (2007): "The technologies studied here can in fact be used as tools to support the processes of both empirical and thought experiments since scientific *reasoning* is the common underlying goal" (p. 149). In other words, technology can be used either as the main medium for a particular investigation, or as a supporting tool for traditional investigative activities to achieve a balance of simulation use, hands-on experiments, and thought experiments. The other technical disadvantages can mainly be overcome with proper planning and, in time, will become moot as technology becomes more efficient and ubiquitous.

Kim, Yoon, Whang, Tversky, and Morrison (2007) discuss disadvantages of animations as opposed to static graphics. Although these disadvantages are stated directly in relation to animations, they may apply equally to simulations, which utilize animations as components:

- since animations change, they cannot be inspected and re-inspected (by the learner) the way static diagrams can,
- the information is fleeting and hard to process,
- motion attracts attention so less important, but more active aspects of an animation may override attention,
- novices may not know which are the important features to attend to (too complex), and
- complexity may overwhelm learners, causing them to give up (p. 261).

In summary, Kim et al. (2007) suggest that, “it is possible that animations may distract attention and interfere with deeper processing, therefore affecting comprehension negatively” (p. 261).

Newton and Rogers (2003) propose that complementing science lessons with information and communication technology (ICT) tools support learning in two important ways. Firstly, the “intrinsic properties” of the ICT tools offer advantages by saving time, such as allowing for the handling of large amounts of data and automating operations. Secondly, ICT tools offer “potential learning benefits” such as clearer thinking and the promotion of interpretive skills: “It is the decisions made by teachers (and pupils) concerning the manner of use that are critical to securing these additional benefits” (p. 114).

Hennessy et al. (2007) concluded that ICT tools, specifically simulations, impact pedagogy and lead to effective teaching and learning if three guidelines are observed.

First, students must be allowed to manipulate the simulations *themselves* and must be given time to explore “What if?” scenarios that are not the main focus of the lesson. Second, teachers should point out imperfections or simplifications in the simulations and have students research them to clarify understanding and promote meaning-making. Third, use of the simulations must be differentiated for more and less able students such that less able students focus on the visual representation of the concept being simulated and more able students conclude their interactions with the simulations by investigating the underlying model of the simulation. This third guideline allows more able students to gain even more understanding by being given the opportunity to critique the principles upon which the simulation is designed and the algorithms or short-cuts that the simulation must make in order to represent real-life events.

The research of Hennessy et al. (2007) has been carried forward by Cronje and Fouche (2008), who sought to answer three questions with their study: the differences in the mental models between the learners who use simulations and the designers who built them; the ways in which learners navigate simulations; and the amount of visible growth in learners’ mental models caused by the use of simulations. Cronje and Fouche (2008) use the term “mental model” to refer to both the mental representations that form the knowledge structures that users apply to a computer-user interface, and the cognitive structures that users possess and construct regarding the phenomenon being represented within the interface. In my investigation, I will differentiate these by referring to the former as “interface mental models” and the latter as “cognitive models”. In their study, Cronje and Fouche (2008) collected data from twelve grade ten science students who were selected in order to form the following sample. Three female students and three male students were chosen from a “technology-enabled” school such that there was a male and female student at each level of three science academic levels: low, medium, and high. The same selection was made of three female students and three male students from a “disadvantaged” school. In the study, the researchers designed their own simulation, complete with background software that recorded the actions that the students performed on the simulation as they navigated their way through it and the amount of time the students spent accessing the simulation. The students were also asked to draw sketches of their perspectives of two scientific concepts both before and after using the simulation. Cronje and Fouche (2008) specifically used only sketches, and not more detailed representations like concept maps, because of “practical considerations, and data saturation” (p. 569). Finally, a questionnaire was administered to the students.

Cronje and Fouche (2008) arrived at three conclusions using a framework based on the students’ mental models. Firstly, there should be an alignment of the interface mental models of the designers of the simulation with the students who use the simulation. The greater the alignment, the more successful the students were at improving their cognitive models of the knowledge domain being simulated. Secondly, the navigation through the simulation and the time allowed to access parts of the simulation should be controlled to a level that is dependent on the ability of the student. If less able students are allowed to jump from one concept to another in any order, then they can become lost or frustrated. Conversely, if more able students are forced to work methodically through content that they already know well, then they can become bored or they may waste their time. Thirdly, “significant and fundamental changes” (Cronje & Fouche, 2008, p. 579) occurred in the mental [cognitive] models of the students, something that was particularly evident in the pre- and post-program exercises used to represent students' mental models.

Cronje and Fouche (2008) suggest that further research into the mental models of learners using simulations would be a useful way for teachers to determine student needs when the teachers select appropriate resources, and sequence and structure learning activities.

1.1.4 Area of Interest

Two of the movements discussed in this chapter that are influencing today's classrooms are the shift in support for constructivist learning theories, and the need for schools to be more personalized with regard to instructional design and pacing, including the identification of the need for students to acquire *21st Century Skills* (Ang, Avni, & Zaphiris, 2008; Çankaya & Karamete, 2009; Cronje & Fouche, 2008; Downing, 2001; Gholson & Craig, 2006).

The need to personalize content and pacing and to infuse 21st century skills into classrooms suggests that the role of the teacher needs to become much more one of a facilitator rather than a transmitter. McCoog (2008) asserts that, to generation Z, those students born after 1990, "Digital technology…is almost a birthright, and schools must accommodate that" (para. 3). McCoog (2008) continues that teachers must teach our students, "the way they learn, using 21st century skills" (para. 6), and that students' opinions should be considered as guiding principles not only during lessons, but also during the planning of lessons. This supports the *social* constructivist's main tenet, that the knowledge created by a learner is governed by the socio-cultural frame of reference of each learner, and makes a strong argument that the tools used in the classroom should conform to the individual needs of each student, and should therefore be designed to be used with specificity of learning objectives in mind, but also an openness that allows generality of access.

While the shift toward teaching methods that support constructivist learning theory seems to be beginning to occur in schools, perhaps more in the elementary and junior high levels than in high schools (White-Clark, et al., 2008), this shift has been difficult for teachers. I have seen evidence of this difficulty on many recent visits to schools where I have witnessed many senior high school teachers using a didactic approach as the main teaching method in their classrooms, and the interactive whiteboard in the classroom is used for nothing more than taking attendance (students touch their names as they walk into class so that the teacher's record book is automatically updated). This shift in teaching methods will take time as educators advance from those methods they were taught with, which can become a propagation of out-dated methods.

Personalizing content and pacing for students demands that tools and aids be available at all times that allow not only teachers to customize programs to students, but that allow students to customize programs for themselves. It is imperative that these tools and aids be pedagogically sound, and that they are designed with cognitive theory in mind.

1.2 Purpose of This Research

I discussed three current movements in education in the previous section: the changing role of the teacher, the growing importance of 21st century skills, and the integration of technology into instruction. I also presented the educational simulation as one possible tool to assist with the advancement of these movements. There is a fairly extensive body of research providing evidence that simulations can promote conceptual change in students. However, for each popular science topic, there are a great number of simulations available to choose from. A teacher may need guidance when choosing which simulation is most beneficial to learning.

The purpose of this research is to identify the conceptual changes that occur in students when they use physics simulations, and to also examine whether there is a relationship between how engaging a simulation is to students and the amount of conceptual change students experience while using it. A secondary goal of this research is to possibly assist teachers with choosing simulations that are effective educational tools. As teachers embrace technology in their classrooms more and more, the use of such tools as simulations to supplement the teachers' instructional methods is becoming more widespread. It is important to educators to be able to select the best resources to use with their students, and being aware of characteristics of simulations that hold more merit than others may allow educators to choose the best simulations.

The primary research question of this study is "What conceptual changes do we see when students use physics simulations?", while a secondary question is, "Do simulations with engaging characteristics seem to promote conceptual change in students?"

1.3 Delimitations of This Research

This study was delimited in several ways because of the resources available to the researcher and the constraints of conducting research in schools. First, the study sample was kept to students at one school in west-central Alberta. Securing permission to conduct research with students in schools is difficult in many jurisdictions, especially in those large, urban jurisdictions that are co-located with universities. I chose to avoid those jurisdictions and seek a school district that was not typically burdened by research requests from post-secondary institutions. This also meant that travel was involved, and so in order to limit expenses, I decided to make contact with one large, but more remote, school jurisdiction to request access to student-participants. In the end, permission was granted to access one school in the jurisdiction. Second, the sample size was expected to be between six and ten since the number of science students that I had access to at the school was limited, and it wasn't likely that I would have been able to obtain a larger sample. This small sample size was chosen so that the data could be collected on one, two-day visit to the school. One visit limited the costs to the researcher, given that no resources were available to conduct this research. This sample size also aligned with the study that this research is related to (Cronje & Fouche, 2008). In that study, the further research recommended was qualitative research into the mental models of learners. In order to collect qualitative data for this research, it was necessary to keep the sample size small for one researcher to manage. Third, there were two rubrics that I could have used to score the students' concept maps, one holistic in nature and the other one analytic. While either rubric would have been suitable for this research, I chose the analytic rubric because it could be applied fairly reliably (consistently) by one scorer. The holistic rubric would have required more scorers and this would have meant training processes and reliability processes would need to have been designed, thus increasing the length of time spent analysing the data. Finally, three simulations were chosen for the research for two reasons: three simulations allowed for a diversity of functionality and look; and using only three simulations kept the time burden on the participants reasonable while still allowing them enough time to access a reasonably full range of features within each simulation.

CHAPTER 2: LITERATURE REVIEW

This literature review focuses on three areas relevant to this research. First, it reviews the dominant views in scholarly literature related to constructivist learning theory and conceptual change. Next, it discusses the literature associated with techniques for measuring conceptual change with a specific focus on concept mapping. Finally, the literature review examines simulation design principles that may support conceptual change.

2.1 Constructivist Learning Theory and Conceptual Change

The positivist or objectivist thinking in science teaching is that students come to the learning situation as vessels that are ready to accept the knowledge that is about to be imparted upon them; if the teacher is careful and pours the knowledge at just the right rate and doesn’t slop over the edges, optimal learning will take place. This view of science teaching is that the only true methods of gaining scientific knowledge are through dialectic, and mostly didactic, instruction, empirical experimentation, and thought experiments (Niaz, 2011; Reiner & Gilbert, 2004). Novak (2010) explains positivist instruction as thinking that, “there is ‘one true answer’ to questions, and these answers will be self-evident if we simply observe and record events carefully” (p. 57).

Learning theory in the twentieth century went through two major movements, behaviourism and constructivism, as psychologists attempted to develop theories to explain what situations are most conducive to learning and what the mechanisms are by which human beings learn. The following sections present the research and theories that laid the groundwork for constructivism.

2.1.1 Behaviourism

Early 20th century learning theory focused on behaviourism, a movement that was based mainly on the work of three prominent figures: Ivan Pavlov, for his work in classical conditioning; John Watson, for establishing the principles of behaviourism; and B.F. Skinner, for his work on operant conditioning and reinforcement (Miller, 1993; Pritchard & Woollard, 2010). Behaviourists believe that their research into learning should be restricted to what is observable and measurable, and any questions about consciousness should be avoided (Fletcher, 2009). While the theory is able to explain changes in behaviour to a point, it does not adequately explain cognitive development, nor was this the goal of behaviourists. For example, if a student was told that twelve multiplied by twelve is 144, and for a period of time he was repeatedly asked the question and given positive reinforcement intermittently when he answered correctly, the behaviourist would conclude that the student had learned this concept: he displayed the appropriate behavioural response to the given stimulus. However, this observation is outwardly focussed on the behaviour of the student, not inwardly focused on the processes used by the student to answer the question, or the understanding of the concept that the student possessed. Does the student understand that this means twelve groups of twelve objects? Can he apply it to a situation, such as calculating how many doughnuts are there in a dozen boxes of doughnuts, each containing a dozen doughnuts? Behaviourism thrived in the education establishment until the 1960's, at which point several questions that remained unanswered about its efficacy to explain learning phenomena decreased acceptance in the movement. Is reinforcement necessary, or can a response to a stimulus sometimes occur without reinforcement? Can learning occur simply because of being situated in an environment (Miller, 1993)? What are the roles of, “intra-individual, psychological explanatory mechanisms (e.g., perception, memory, conscious deliberation) mediating between the environment and those higher processes” (Bargh & Ferguson, 2000, p. 926).

While behaviourists confined themselves to explicit, observable phenomena, and avoided any attempts to theorize about the workings of the mind, constructivists believed the exact opposite: the important considerations were what was taking place in the mind, and the manifested behaviour may not be a valid indicator of what the mind is thinking.

2.1.2 Piaget and the Foundations of Constructivism

Constructivism is not a theory about learning, but rather an epistemology, a philosophy about the nature of knowledge (Pelech, 2010; Pritchard & Woollard, 2010). Although it began as a philosophical movement in the last half of the twentieth century, its roots can be found much earlier. Constructivist philosophy can be found in ancient writings of Gautama Buddha, Heraclitus, Lao Tzu (Pritchard & Woollard, 2010), Confucius, Plato, and in Aristotle’s statement, “we know things as a result of induction” (Pelech, 2010, p. 9). Through medieval and renaissance times, constructivism can be found in the writings of many people: Giambattista Vico, who believed that a person’s context influenced how he learned the natural sciences; Immanuel Kant, who wrote that the senses determined how we personally understand the part of the universe that we are able to understand, and we accept that there is an ontological reality, a part of the universe that is beyond our understanding; St. Augustine, who connected learning to experiencing; St. Thomas Aquinas, who recognised the role of the senses in knowledge construction; and John Locke, who believed that the senses were important to learning, and that learning is an act of the mind involved in combining ideas (Fletcher, 2009; Pelech, 2010; Pritchard & Woollard, 2010; von Glaserfeld, 1998).

It is generally accepted that the constructivist movement began in the 1960s, based mainly on the work of the psychologist who coined its name, Jean Piaget (Pritchard & Woollard, 2010; von Glaserfeld, 1995). After years of research, he proposed a theory of human psychological development that consisted of four stages. These stages began at birth, and most humans reached the fourth stage sometime during mid to late adolescence: the sensorimotor stage, from birth to two years; the pre-operational stage, from two to seven years of age; the concrete operational stage, from age seven to eleven; and the formal operational stage, from age eleven to fifteen (Miller, 1993). The ages provided for these stages were Piaget’s guidelines, based the findings of his research. During the sensorimotor stage, children start with the ability to sense surroundings, and they develop the ability to organise it sufficiently such that they can act in order to make adjustments to objects and events. In the pre-operational stage, children develop the ability to use symbols, such as gestures, words, and images, to organise and communicate to others. In the third stage, the concrete operational stage, children develop the ability to internalize actions and employ logic in situations they are familiar with. Finally, in the formal operations stage, children develop the abilities to apply logic and reasoning to situations that they aren’t familiar with, much like the scientific method (Miller, 1993). While individuals move through these stages at different rates, one must remember that the transitions are not abrupt , and are based on four factors: maturation, experience with objects, social experience, and equilibration (Miller, 1993).

Beyond this theory of psychological development, Piaget developed his theory of *genetic epistemology,* and a primary tenet of that theory was the idea that humans possessed a set of rules, which Piaget called "schemas", by which everyday surroundings are interpreted. Schemas are "integrated networks of knowledge which are stored in long-term memory and allow us to recall, understand and create expectations" (Pritchard & Woollard, 2010, pp. 10-11). A schema represents all of the knowledge a person has of a topic or object, and this schema is used not to produce a copy of reality, but for classification, analysis, evaluation, knowledge-building, and prediction, especially for the purposes of adaptation (Pelech, 2010; von Glaserfeld, 1998). At a simple level, a schema can represent what a child knows about an apple: it is a fruit, it is red, it has a skin, it grows on trees, and it is somewhat sweet. When this child encounters a variety of apple that is green, such as a Granny Smith apple, she discovers that it looks like an apple, it has a skin, and it is a fruit. However, it is green and it is not as sweet as other apples she has tasted. According to Piaget's development theory, depending on the stage that the child is at, the child may incorporate this new type of apple into her schema, or she may not, depending on the context. A person's schemas are constantly evolving, and growing links to other schemas that are related to it so that the individual can adapt more easily to his or her environment (Miller, 1993; Pritchard & Woollard, 2010).

While schemas provided the lenses through which an individual was able to understand his or her environment, Piaget proposed that there are three processes by which humans learn from their surroundings. When a person is in familiar surroundings, they are in a state of equilibration. However, when that person is confronted with something new, something that is not immediately familiar, the person experiences disequilibration: the new stimulus does not immediately fit with a personal schema. Piaget would say that this person would experience one of two processes to reach equilibration again, either assimilation or accommodation. Assimilation is the process by which the person tries to fit the new stimulus into an existing schema, such that the schema is more inclusive, but qualitatively unchanged. In other words, the person is able to find a schema that the new stimulus "fits" with. Accommodation is the process by which the person must either modify an existing schema to make the stimulus fit, or must create a new schema for the stimulus. In the example given above using the Granny Smith apple, the person experienced disequilibration when she saw and tasted the green, slightly sour apple. It is likely that she would be able to assimilate this new apple into her apple schema.

Piaget's theory of genetic epistemology laid the foundations of constructivist philosophy by providing a psychological development theory that was supported by research, and processes of learning that accounted for acquiring and processing information.

2.1.3 Radical Constructivism (von Glaserfeld)

As was stated earlier, Piaget was the first psychologist to coin the term constructivism, referring to his belief that knowledge was not simply taken in, but rather a person actively constructed it. In the last portion of the twentieth century, Ernst von Glaserfeld took the ideas of Piaget's genetic epistemology and constructivism and added to the work. He began doing so because he felt that psychologists were dismissive of Piaget's theories, and educators were using Piaget's term "constructivism" in a way that demonstrated a misunderstanding of the theory (von Glaserfeld, 1998). He began adding the word *radical* to constructivism in order encourage people to look for the deeper meaning in the theory. While coining the term and forming the movement of radical constructivism, he also focussed more on epistemology, unlike Piaget who focussed on developmental psychology. He formed the epistemology of radical constructivism based on two tenets. First, knowledge formation is not a passive activity; it is actively built by the subject (Pritchard & Woollard, 2010; von Glaserfeld, 1998). In a learning context, this means a student must be actively engaged in a situation for learning to take place (Pelech, 2010). Second, learners possess prior knowledge, and the purpose of knowledge construction is for learners to adapt to and organise themselves within their reality (Fleury, 1998; Pritchard & Woollard, 2010; von Glaserfeld, 1998). von Glaserfeld is very clear about the ambiguity of the term *reality* used here and how it is used with regard to the second tenet. There is one ontological reality that lies beyond knowing, and a tangible reality that one can know and experience, and it is within this latter reality that people derive all of their knowledge (von Glaserfeld, 1998). This adaptive function is important to constructivist philosophy, and one can see Piaget’s influence in it: schemas, and the learning processes of assimilation and accommodation.

2.1.4 Social Constructivism (Vygotsky)

Piaget formed the roots of constructivism, based on the idea that humans mature cognitively through their actions on their environment and on other people, and von Glaserfeld further fleshed out the philosophy with radical constructivism. During the time Piaget was forming these roots in the early twentieth century from his research with children, Lev Vygotsky was independently developing a constructivist epistemology in the USSR, and so it was unavailable to much of the western world of educators until the latter quarter of the twentieth century.

Similar to Piaget's and von Glaserfeld's philosophies, Vygotsky's theory regarding epistemology proposes that knowledge is constructed by people rather than passively received, and it is built upon pre-existing knowledge possessed by the person. The major difference with Vygotsky's theory is that knowledge has a social component: we build knowledge through discourse with others, and that constructed knowledge is dependent upon our particular socio-cultural context (Pelech, 2010; Pritchard & Woollard, 2010), from which human behaviour cannot be understood independently (Miller, 1993).

An important feature of Vygotsky's theory is his Zone of Proximal Development, or ZPD. The ZPD is, "a notional area of understanding or cognitive development that is close to but just beyond a learner's current level of understanding" (Pritchard & Woollard, 2010, p. 14). In order to make progress, learners must be helped to move into this zone by someone who is knowledgeable in that zone through social interaction. This process of helping the learner move into the ZPD is known as scaffolding, which is a "measured and appropriate intervention" that may consist of a range of approaches that may involve "human intervention,…the provision of materials, or the opportunity to interact with peers or even a computer program" (Pritchard & Woollard, 2010, p. 38). Once the learner moves into that zone, a new ZPD is formed for the learner such that capacity to learn is possible.

Vygotsky's theory further elaborated on the social-context aspect of the theory by explaining that learning took place on two planes or levels: the interpsychological level, or social plane; and the intrapsychological level, or internal plane. Vygotsky (1978) wrote that:

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

At the interpsychological level, development first takes place as the person interacts with other people such that the learner observes, listens, and imitates, while the knowledgeable other directs, corrects, and challenges. At the intrapsychological level, context becomes internalized and the learner becomes more familiar and competent (Pritchard & Woollard, 2010).

The two branches of constructivism described so far, von Glaserfeld's radical constructivism, and Vygostsky's social constructivism, share some primary tenets. However, they differ in some fundamental approaches to development and learning that provoke debate amongst proponents. Zhou (2002, p. 29) summarised those differences using the table shown in Table 1.

Table 1

A Comparison of Piaget's and Vygotsky's Theories

	Piaget	Vygotsky
Origin of mental function	Individual active experience with the physical world or other persons	The society and culture children live in
Mechanism of construction	Invented by the child-in-action	Internalized by the person-in society
Typical behaviour of construction	Any physical and mental action	Cultural apprenticeship, activity with more cultured adults or peers
Function of interaction	Source of disequilibration and thus development, source for social knowledge	Source of models of what constructions should look like
Learning and development	Development precedes learning; development is the driving force for intellectual maturation	Learning leads to development; learning is the driving force of intellectual maturation
Language and thought	Language acquisition reflects intellectual development but does not produce it; language can facilitate intellectual development but is not necessary for it	Language acquisition results in qualitatively improved thinking and reasoning and thus intellectual development

Students arrive in science classrooms with their own individual understandings of how the world around them works. There is a vast body of literature describing that these preconceptions "may differ substantially from the ideas to be taught, that these conceptions influence further learning and that they may be resistant to change" (Driver, 1989, p. 481). Additionally, there is evidence that supports Vygotsky's theory that there is a socio-cultural effect at work as well. Miller (1993) found that children not only performed better on memory tasks when there was some sort of interest to them, they also performed better on memory tasks when the context fit with their socio-cultural framework. For example, when children were presented with pictures of adults at work, it was very common for the children to incorrectly recall details about the pictures, such that incorrect recollections reflected traditional beliefs of the society that the students were members of: a woman driving a truck was often recalled as being a man, whereas as a man doing clerical work was often recalled as being a woman. What is suggested is that knowledge is something that exists only in the mind of each learner, and for that knowledge to exist, a learner must construct it. This constructed knowledge is affected by the learner's preconceptions and socio-cultural beliefs and experiences, and is therefore individual, yet shared with other members of the learner's community.

When constructivist epistemology is applied to pedagogy, three general themes emerge. First, the learner needs to be engaged in order to construct knowledge. Second, the learner brings pre-conceptions and socio-cultural contexts to the classroom, and new knowledge is constructed upon these. Third, the teacher must also be engaged and provide challenging, creative environments for students, while providing the students with the autonomy to explore those environments (Pelech, 2010; Pritchard & Woollard, 2010). These points form the first part of an argument for investigating the conceptual changes that result from using simulations in high school physics classes. These simulations are typically designed to allow the user to explore a general concept in a non-linear, safe, and fairly authentic way:

> The conventional approach to school experimentation leads the learner through a well-structured set of instructions derived from a rigid definition of experimentation. It starts with making observations, collecting data, proceeds to

> the analysis of the data through mathematical manipulations such as graphing or algebraic formalism, and concludes with the production of generalizable inferences (Reiner & Gilbert, 2004, p. 1820).

This approach is meant to lead a student to the one, true result: a positivist approach. It is also not true to the purpose of experimentation in science, which is to test and reason. Hennessy et al. (2007) propose that technologies such as computer-based applications, web-based simulations, and interactive whiteboards “can in fact be used as tools to support the processes of both empirical and thought experiments since scientific reasoning is the common underlying goal” (p. 149). Since web-based simulations allow the student-user to control the behaviour of the simulation, and therefore the outcomes, it is unlike the experiments noted by Reiner and Gilbert.

It is necessary to add a final note on the importance of a shift to more constructivist methods in the classroom. This does not represent a wholesale shift, meaning a complete divorcing of ourselves as teachers from didactic methods. Lecture still has an important place in many lessons, especially where student-led inquiry is unsafe, inappropriate, or inefficient. To be illustrative, a chemistry teacher would not likely allow students to design their own lesson to investigate the handling of stock acids in the lab; a didactic approach would be much more appropriate. Similarly, a regime of behaviourist conditioning may be called for if the situation is one where the goal is training for a response, such as paying attention to a teacher in a physical education class when a whistle is blown (Pritchard & Woollard, 2010). Rather, what I am proposing is that a time is coming when there needs to be a balance of instructional methods, and those with foundations in constructivist learning theory need to take a greater focus than they have in the past. New technologies, such as simulations, may assist teachers with incorporating more constructivist experiences into their learning environments.

2.1.5 Models for Conceptual Change

The focus of the four previous sections was on psychological development, and epistemology, and theories of learning and cognitive development. In those sections, the basic ideas presented were that students come to learning situations with pre-existing knowledge, and they construct new knowledge when they are both engaged and able to rectify the new knowledge with the pre-existing knowledge and, depending on the branch of constructivism one follows, the socio-cultural beliefs and context that frame the pre-existing knowledge and the learning situation. I tend to favour Vygotsky's perspective, and in this section, I will use the social constructivist approach for a foundation for exploring mechanisms of the process of conceptual change. In a teaching context, if one can understand the mechanism by which students undergo conceptual change, one may be able to promote it.

Jonassen (2009) begins defining conceptual change in the following way:

> Learning is [among a list of other things] conceptual change. Learning is a process of making sense out of domain concepts in such way that they develop coherent conceptual structures. In order to make meaning, humans naturally organize and reorganize their naive models of the world in light of new experiences. The more coherent their theories are in the world, the better are their conceptual structures (p. 16).

The key to this definition is the focus of the change. When discussing conceptual change, not only are changes to concepts being considered, but how they are personally organized by individuals in order to make meaning of their own “lived, tangible reality” (von Glaserfeld, 1998, p. 24). Jonassen (2009) concludes the definition with the following points:

> Conceptual change is a process of reorganizing personal conceptual models. From an early age, humans naturally build simplified and intuitive personal theories to explain their world. Through experience and reflection, they reorganize and add complexity to their theories or conceptual models. The cognitive process of adapting and restructuring those models is conceptual change. Because conceptual knowledge is the basis for conceptual change, it must be integrated into any architecture of human cognition (p. 19).

By this definition, if one is to understand the mechanism by which conceptual change occurs, one must not only understand how humans develop psychologically and how they construct knowledge, one must also understand the impetus for a learner to need to change the organization of his or her cognitive structures. As Posner, Strike, Hewson, and Gertzog (1982) put it, “learning…is best viewed as a process of conceptual change [and the] basic question concerns how students’ conceptions change under the impact of new ideas and evidence” (p. 212).

Piaget’s theory of genetic epistemology contains elements that are applicable to both psychological development and scientific development (Miller, 1993; Zhou, 2002). Recall that, according to Piaget, when a person encounters a stimulus that is inconsistent with an existing cognitive structure, one of two processes occurs. If the stimulus is similar to an existing cognitive structure, equilibration is maintained and the person assimilates the new stimulus into the existing cognitive structure. If the stimulus is too dissimilar from existing cognitive structures, the person experiences disequilibration and accommodation must occur. Accommodation is the process of modifying an existing cognitive structure to incorporate a new stimulus, or constructing an entirely new cognitive structure to represent the stimulus. Once accommodation is complete, the person reaches a state of equilibration once again.

In 1970, Thomas Kuhn published a theory to explain how scientific theories change. Kuhn’s theory views changes to scientific theories as “revolutions”, brought about by “anomalies” that cannot readily be incorporated into existing scientific theories. Kuhn’s theory, in a very simplistic form, has five states, and the states are parts of a cyclical process. The first state is called pre-science, and it is that time preceding the formation of agreed upon science in an area. Over time, ideas become structured and supported by research, and the second state, normal science, is achieved. Kuhn (1970) defined the concept of normal science as “research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice” (p. 10), and so the state of normal science is that time when the community of researchers and practitioners in an area of science are at a state of equilibrium: phenomena can be explained and interpreted and predictions can be made. A concept closely related to normal science is the paradigm, which Kuhn used to refer to laws, theories, applications, and instrumentation–Kuhn also refers to these as “achievements”–that the scientific community is committed to. Normal science and paradigms are successful if they have two characteristics: they are sufficiently unprecedented such that they draw a significant and committed group of followers from competing activity; and they are sufficiently open-ended to leave the followers questions to test and resolve. During normal science, scientists inevitably encounter phenomena that don't fit with the currently agreed upon paradigm or normal science. Kuhn called these anomalies, and they are the key to advancement of science. If the science community is able deal with the anomalies as "little puzzles" and modify the current paradigm in order to explain the anomalies, then this is called assimilation and normal science is resumed. These assimilations are both "destructive and constructive" such that parts of the paradigm must either be discarded or changed, while replacing those discarded parts with new ones. This ensures that the paradigm is either able to account for a wider range of phenomena, or to account with greater precision for those phenomena that were previously known (p. 66). However, there are some anomalies that cannot be assimilated: they remain unexplained for some time. Scientific communities are able to withstand and defer a small number of anomalies if the paradigm is strong. However, when anomalies become too numerous or troubling to the community, they enter the third state, called crisis. During the state of crisis, new anomalies may emerge, and new hypotheses may be proposed. If a new hypothesis satisfies the two characteristics given above, meaning it is sufficiently attractive and it allows for more research to advance the discipline, then the fourth state is reached: revolution. One of the examples that Kuhn uses to illustrate his theory to this point of the discussion is Copernicus' announcement of a heliocentric theory of the universe. Among the many anomalies that the Ptolemaic geocentric model had difficulty explaining were the phases of the moon and retrograde motion of the planets. Copernicus proposed his theory to account for these anomalies and others, which spurred vehement debate amongst scientists and philosophers of the time. The church became involved as well when Galileo published empirical support for the heliocentric theory, which went against the geocentric theory supported by the church, and he was subsequently tried and convicted of heresy. This demonstrates Kuhn’s idea that scientific revolution is not always based on rationality, but also includes social factors of those debating. Eventually, the heliocentric theory gathered enough followers to be considered as a generally accepted new paradigm, and so this exemplified Kuhn’s final stage, called new normal science. Kuhn’s theory of scientific revolution is shown in Figure 1.

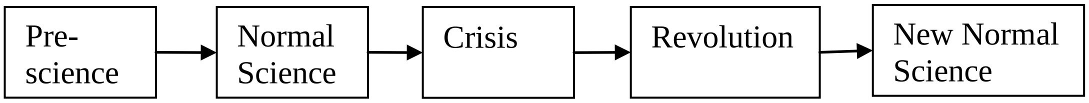


Figure 1. Kuhn’s theory of scientific revolution.

While Kuhn’s theory is related to the nature of change with respect to paradigms in science, and Piaget’s theory of genetic epistemology is related to the development of human psychology, the two have stages that are strikingly parallel. Zhou (2002) summarized the theories in two diagrams, and these are presented in Figures 2 and 3.

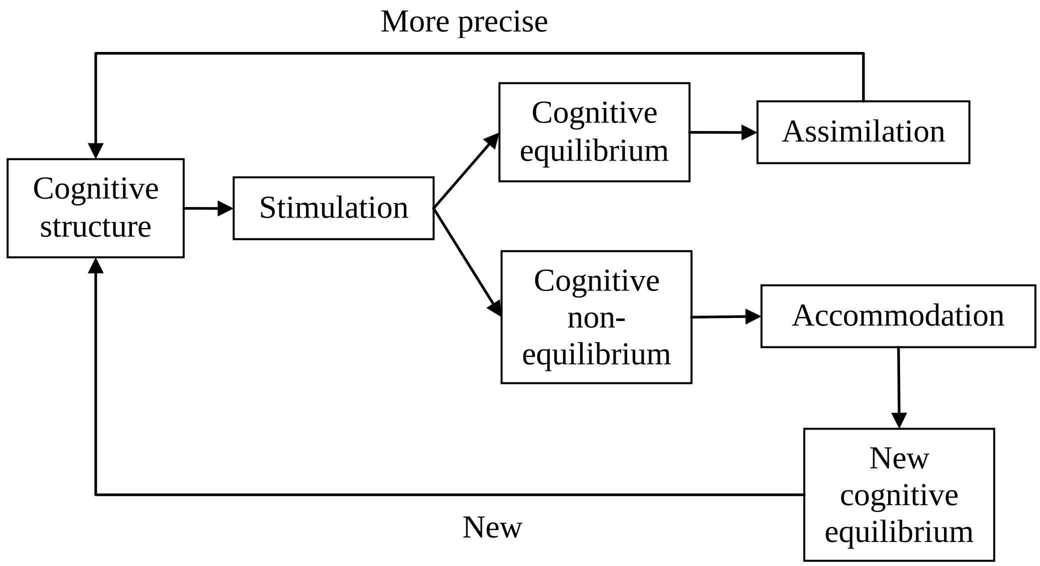


Figure 2. Piaget's psychological development theory (Zhou, 2002, p. 37).

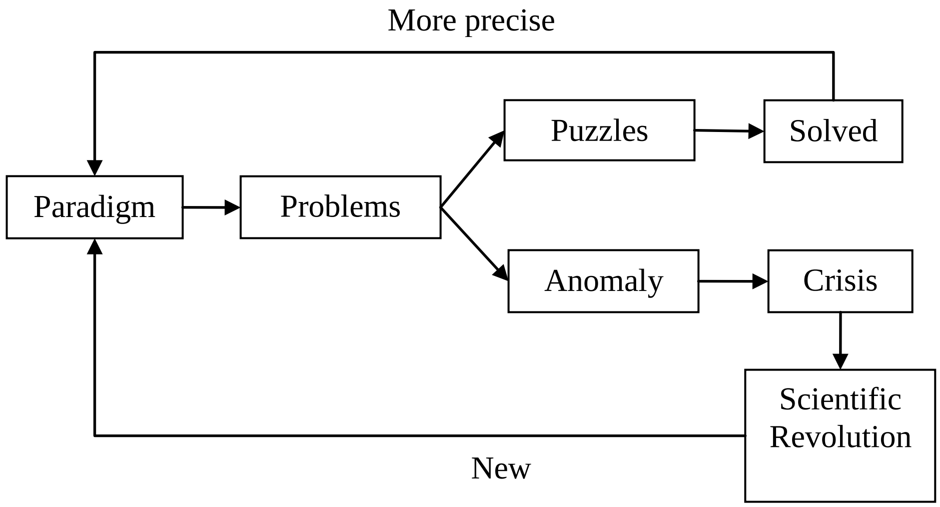


Figure 3. Kuhn's scientific development theory (Zhou, 2002, p. 37).

The parallelism of these two theories has two implications for understanding conceptual change in students. "First, knowing the conceptual obstacles in the historical development of science can help us predict students' preconceptions. Second, the history of science can, in some measure, throw light on the individual learning process and a suitable sequence of curriculum" (Zhou, 2002, p. 37).

Posner et al. (1982) proposed that conceptual change is analogous to change in science, and learning occurs similarly to the paradigmatic change represented in Kuhn's theory. Posner's model of conceptual change was based on the assumption that there are two types of conceptual change. When a learner uses existing concepts in order to cope with new phenomena, the process is one of assimilation. When the learner's current concepts, which Posner et al. (1982) called the learner's conceptual ecology, were inadequate, a replacement or reorganization of concepts was necessary, which Posner et al. (1982) termed accommodation. The model is based on the presumption that conceptual change occurs "against the background of the learner's current concepts" (Posner, et al., 1982, p. 212), the conceptual ecology.

Posner et al.'s (1982) research had two foci: investigate the conditions under which accommodation takes place, and determine the features of the learner's conceptual ecology which govern the selection of new concepts. His study proved successful on the first focus, but less so in terms of the conceptual ecology question. The model that arose from Posner et al. (1982) is based on the four conditions under which accommodation, that significant restructuring of the learner's conceptual architecture, takes place. First, the learner must be dissatisfied with existing conceptions. There must be a collection of unexplained anomalies and a belief that less radical change of concepts will not be enough. Second, the new conception must be intelligible to the learner, such that he or she is "able to grasp how experience can be structured by a new concept sufficiently to explore the possibilities inherent in it" (p. 214). Third, a new conception must appear to be initially plausible, such that the learner sees immediately that there are possibilities for it to solve problems that the predecessor concepts could not. Finally, a new concept "should suggest the possibility of a fruitful research program" (p. 214), meaning a learner should be able to see the potential of the new concept to provide new areas to delve into.

While the Posner model was used by many constructivists until the early 1990s, other learning theorists began to point out its shortcomings. At the time, Pintrich, Marx, and Boyle (1993) pointed out that there was growing disagreement between rational and irrational models of conceptual change, what they termed cold and hot models. Cold models were driven by logic and reasoning, while hot models were driven by personal interests, motivation, and social factors. Pintrich et al. (1993) showed a weakness in the Posner model in that it was cold: it did little to account for personal interest, motivation, and social factors, and as such, they proposed that the model may not be accurate. This began a trend toward "warmer" models of conceptual change, ones that accounted for motivational factors, emotional involvement, value, interest, and social context (Zhou, 2010). One such model was proposed by Dole and Sinatra (1998), the Cognitive Reconstruction of Knowledge Model, or CRKM. Although it incorporates elements of Posner's model, it elaborates to account for personal contexts surrounding preconceptions, motivation, and the message and mode of reception of the new concepts. In the model, Dole and Sinatra (1998) propose that there are three qualities of a learner's preconceptions that influence how likely the learner is to change them: the strength with which the preconception is already formed in the learner; the coherence of the preconception, meaning how well the preconception explains a phenomenon while fitting with other preconceptions; and the learner's commitment to the preconception, which can come from a variety of sources, such as sensory experience, social experience, or cultural background and beliefs. Motivation is also key to the CRKM, and Dole and Sinatra (1998) identified four areas that affect motivation: dissatisfaction, personal relevance, social context, and cognitive need. These four areas can be exemplified by questions. Is the learner dissatisfied with the current preconceptions enough that they desire a change? Is the new concept relevant to the learner, or are they emotionally involved in it? Do the learner's peers show interest, or would it be socially disadvantageous to not be motivated to learn? Is the learner simply one of those people who, by their very nature, are driven to learn new things? Finally, with respect to the message or mode of reception of the new concepts, Dole and Sinatra (1998) list that the information should be comprehensible, coherent, plausible, and rhetorically compelling. This last point, rhetorically compelling, is highly relevant to educators, such that it means that in communicating about a concept, language usage should be familiar, justifications must be convincing and persuasive to the individual, and the message may be dependent on the person delivering it. For example, one individual may find an argument compelling if it is delivered by a passionate speaker, while another may be more easily swayed by a presentation of emotionless data.

Zhou (2010) proposed that the fundamental issue with all of the models, both cold and hot, was that they did not allow learners to become aware of the instructional message before they began their struggle for a conceptual position between new concepts and pre-existing concepts. As such, he proposed a model for conceptual change to be used in science classrooms based on the principle of argument. The key social relationship idea of the model is that the teacher/facilitator is part of the argument on the same level of the student: there is no power relationship. A strength of this approach is that, during the process of argument, a student not only makes his or her beliefs clear to others, but also to himself or herself, which is a metacognitive process. A graphic representation of Zhou's (2010, p. 106) model is presented in Figure 4.

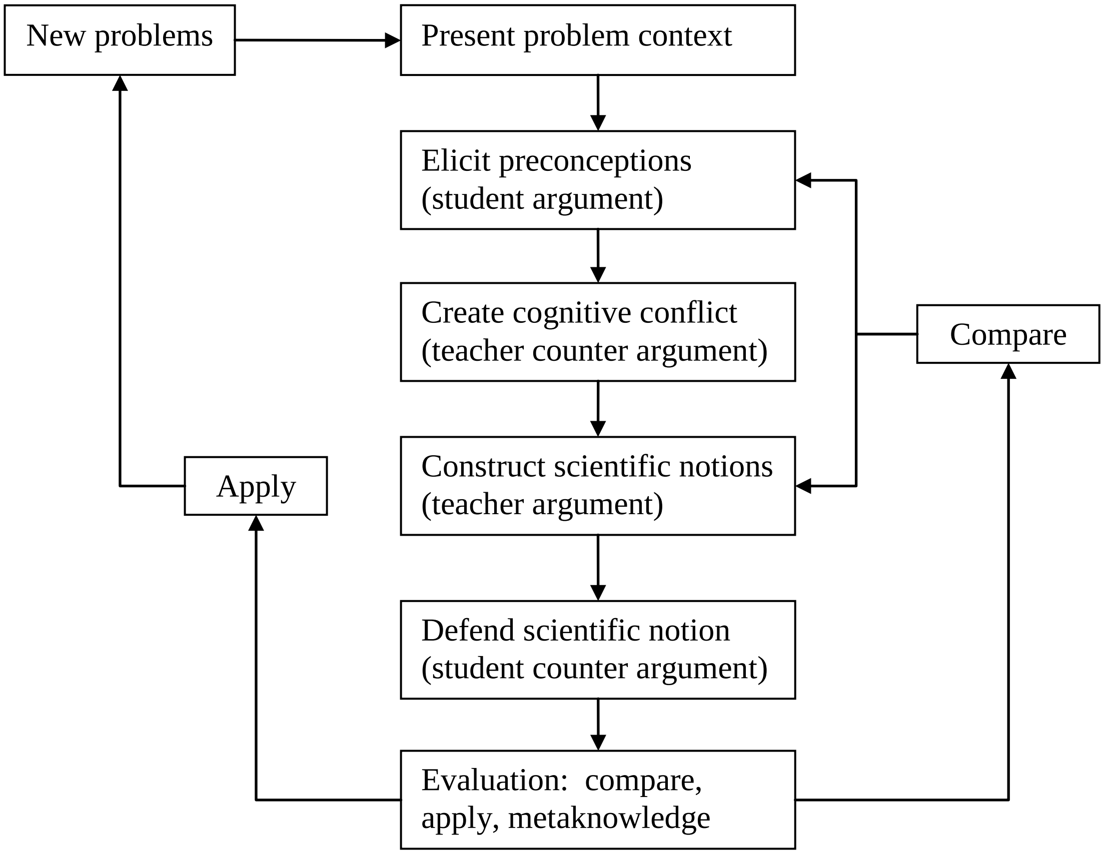


Figure 4. The argument approach to teaching science.

Zhou's (2010) instructional process of argumentation requires highly engaged teachers and students. In the first step, the teacher asks the students to interpret phenomena or watch a demonstration and make predictions. The teacher needs to deliberately choose an activity that will make students' preconceptions apparent. The second step is an extension of the first, calling for further predictions and discussions amongst students regarding interpretations and justifications for phenomena. Once this is done, the teacher introduces cognitive conflict by demonstrating experiments that may give results quite different from the students' predictions. Zhou (2010) points to literature that shows that students do not easily give up on their preconceptions, and often think something is wrong with the demonstration or experiment, and the teacher must avoid jumping to the answers for the students. Instead, the teacher may choose to point out inconsistencies in the students' arguments or interpretations without pointing out what is correct. In the next step, the teacher constructs scientific notions through presenting inquiry activities for the students. This leads to the need to defend the scientific notion. "In a democratic classroom, students are likely to challenge scientific notions at this stage [and] the teacher needs to offer detailed discussion of these confusing phenomena and demonstrate how the scientific conception can apply to them" (p. 107). The evaluation step is where the teacher and students gather the evidence presented to determine which conceptions have persisted, been discarded, and accepted. Overall, the process of argumentation is recursive, and a class of students, or small groups of students, may need to partake in more argument before they are able to apply the new science concepts to new problems.

Simulations may be used by teachers within any of the models that I have presented in order to promote conceptual change in students. For example, in Zhou's (2010) model, a teacher could use a simulation as a demonstration in the first steps to elicit preconceptions and to create conflict that demonstrates that some student predictions and conceptions are inconsistent with reality, and as inquiry and student-presentation tools at the construction and defence steps. Upon resolution of any debate, the simulation could be used at the evaluation stage to bolster those conceptions that are valid and to finalise the rejection of those conceptions that are invalid.

Conceptual change, the process by which students re-organize their cognitive structures with respect to pre-existing concepts to account for new information, is important for educators to understand if they are to have the goal of promoting it. The conceptual change models I have presented in this section provide a basis to begin a discussion on measuring conceptual change, which is the focus of the next section.

2.2 Measuring Conceptual Change and Concept Mapping

One long-term study conducted by Novak (1993) identified three key factors that govern knowledge formation and meaning-making. First, for learning to be meaningful, new concepts and propositions must be assimilated into existing cognitive structures, resulting in greater differentiation of the learner’s conceptual model of a particular knowledge domain (a possible measure of meaningful learning). Second, knowledge is organized hierarchically, and meaningful learning results when new concepts and propositions are fitted into those hierarchies that the learner has already formed. Also, reconciling new meanings with old meanings can correct misconceptions. The third factor is that rote learning does not allow knowledge to be assimilated, and so concepts acquired through rote learning are either never integrated into a cognitive structure, or they are incorporated into a learner’s knowledge structure in a completely arbitrary and, therefore, meaningless way (Novak & Gowin, 1984). Novak (1993) adds that human memory has three distinct systems (sensory, short-term, and long-term memories), and for assimilation to take place, meaning must be made in the short-term memory and then rectified with other cognitive structures in long-term memory. To assist students with knowledge formation and meaning making, Novak developed the tool known as the concept map as way for a person to organize his or her knowledge.

2.2.1 Concept Map Background

A concept map is a visual representation of an individual's conceptual framework of a knowledge domain. An individual can compose a concept map of nearly any set of related knowledge: golfing, rock music, quantum mechanics, motor vehicles, and so on. Concept maps can be used for note-taking in class, recording observations of experiments, studying, and assessment (Lim, Lee, & Grabowski, 2009; Novak, 1991, 1993; Yin & Shavelson, 2008). They are not particularly useful as demonstrations by an instructor unless the learners are actively engaged in creating the concept map (Lim, et al., 2009).

Concept maps are composed of three distinct components: *concepts*, or nouns that represent some quantum of knowledge; *links*, which are verbs or verb phrases superimposed on a line or unidirectional arrow; and *propositions*, which are two or more concepts linked together. Novak (1991) defines a concept as "a perceived regularity in events, objects, or records of events or objects, designated by a label" (p. 45). The word "perceived" is a key part of this definition; misconceptions in the prior knowledge of the individual creating the concept map may be shown as perceived regularities when there actually is no regularity in the concept. Concepts can be either concrete or abstract nouns such as gravity, colour, truck, and golfing. Some examples of links that connect concepts are: "connected to", "represented by", "are", and "composed of". Novak (1991) defines propositions as two or more concepts that are linked together, and the following are some examples of propositions (**concepts** are shown in bold font, *links* are shown in italicized font): **gravity** *is a* **fundamental force**; **Newtons** *are* **SI units**; **rivers** *are composed of* **water** *which is a* **liquid**.

An organizational characteristic of concept maps is that they are hierarchical, with concepts of equal importance, value, or specificity on the same level. There are different models of concept maps, and to illustrate hierarchies, vertical concept maps show concepts of similar generality as being above concepts that are more specific, while radial models of concept maps work outward such that concepts of similar generality are at the same radius from the center and closer to the center than concepts that are more specific.

A concept map outlining the knowledge domain of “projectile motion” is shown in Figure 5. It is not likely complete, nor are any concept maps, for that matter, because they are simply the representations of the cognitive structures of an individual or a group of individuals at a given time and are limited by the level to which the individual or group is able or willing to articulate those cognitive structures. The purpose of presenting this concept map is to provide an example of a concept map that illustrates the components and organizational features described in this section.

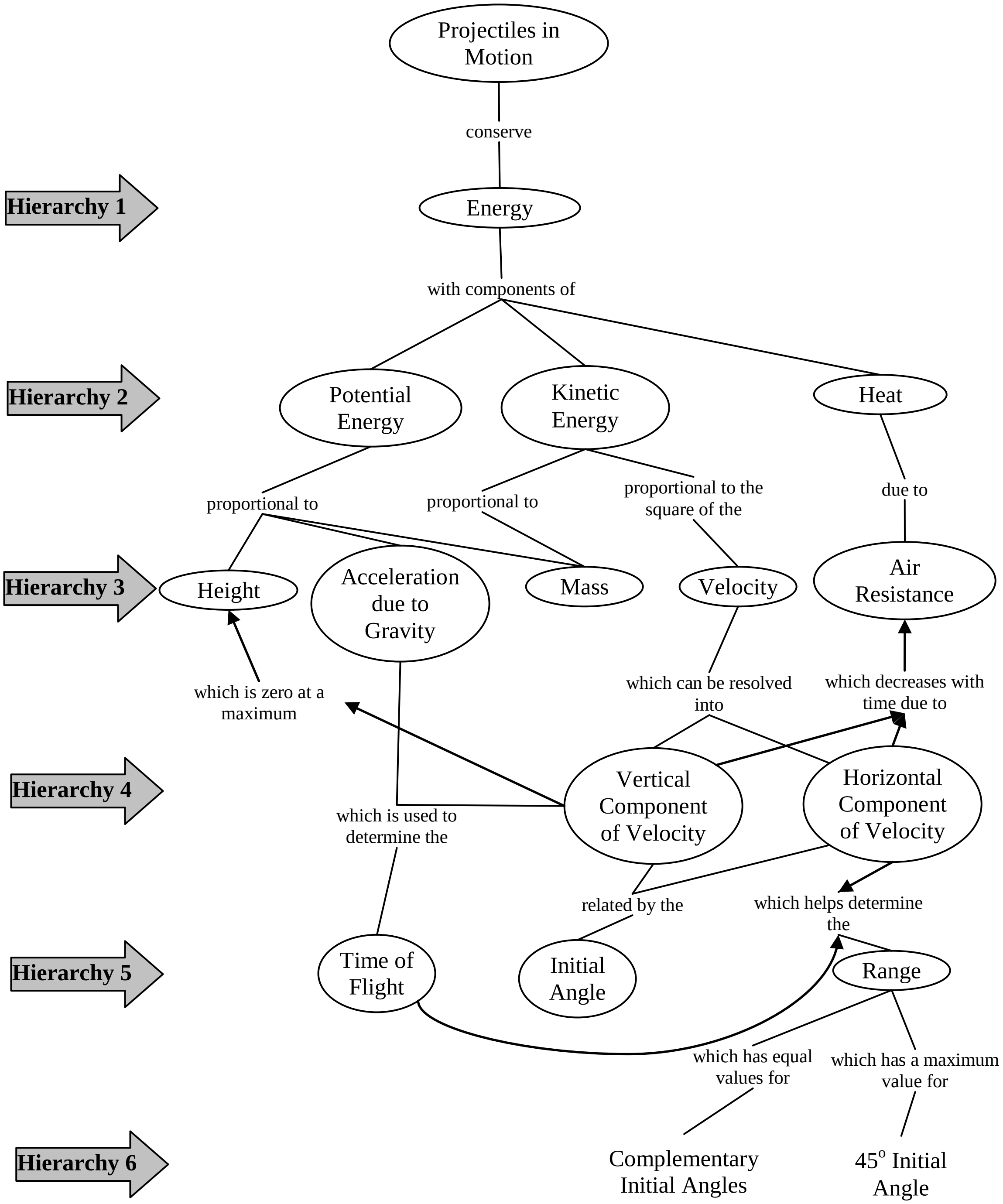


Figure 5. A projectile motion concept map prepared by the researcher, 2009.

The concept map provided in Figure 5 shows all of the components described earlier. The words in the ovals represent the **concepts** associated with the knowledge domain of projectile motion, and the *links* are those words along the lines and arrows that connect the concepts. Novak and Gowin (1984) suggest that simple lines are often sufficient in concept maps, but arrows should be used if the directionality is ambiguous without arrows. For this reason, arrows have been used in the concept map in Figure 5 except in those cases where there is no ambiguity, and directionality is not in question. Some examples of **concepts** in Figure 5 are: **Potential Energy**, **Velocity,** and **Range**. Some examples of *links* or *linking words* are: *conserve*, *due to*, and *which helps determine the*. Some examples of propositions that are formed in the concept map are: "**kinetic energy** *proportional to the square of* **velocity**"; "**horizontal component of velocity** *which decreases with time due to* **air resistance**"; and "**acceleration due to gravity** *which is used to determine the* **time of flight**".

Three other features of concepts maps are illustrated by Figure 5: hierarchical organization, cross links, and examples. The hierarchical organization should show that concepts move from the general at the top to the more specific at the bottom. In Figure 5, the hierarchies are ordered such that the general concept of energy is the first level, which is then split into types of energy at the next level, then the physical quantities used to determine those energies in the next level, then components of those physical quantities, then parameters related very closely to projectile motion, and finally examples occupying the lowest, most specific level. Cross links are those connections between different regions of the hierarchy that may not be readily apparent or may be creative. Often, they represent the synthesis of cognitive structures. In Figure 5, a cross link can be seen by the proposition, “**vertical component of velocity** *which is zero at a maximum* **height**”. Others can be seen where the two components of the velocity have been linked to air resistance. It will be shown soon that these higher order connections are scored highly in the rubrics used to grade concept maps. Finally, concept maps can include examples, which are those specific objects or events, concepts, that are valid instances within the knowledge domain. In the figure, examples are shown as **Complementary Initial Angles** and **45° Initial Angle**. These are concepts, but they are so specific as to be examples of particular situations that are special, and so they are designated as such (Novak & Gowin, 1984). Examples are designated as special concepts in a map by appearing with no ovals surrounding them.

When a learner is creating meaning, he or she is forming new propositions and incorporating those propositions into his or her preconceptions, and the importance of the knowledge that a learner possesses before entering a learning situation is crucial such that new meanings must be constructed on the basis of the knowledge that the learner already possesses (Novak, 1991). It is so important that David Ausubel described it as the single most important factor that influences learning and meaning making (Novak, 2010). It was this idea that guided Novak's research on creating concept maps. Sometimes, learners possess incomplete or incorrect propositions, misconceptions, that make meaningful learning difficult (Novak, 1991), and the difficulty of overcoming misconceptions “may be one reason why teachers often ask students to memorize verbatim concept definitions or problem/solution algorithms” (p. 47).

Novak (1993) describes all meaning-making as event-based, and states that educators “must help…students understand that learning is not an activity that can be shared; it is the responsibility of the learner" (p. 53). The learner must actively take part in the situation either by the weaving together of different parts of external information in a new way by the learner, or by the learner integrating external information into his or her cognitive schema in a meaningful way (Lim, et al., 2009). Novak (1993) found that when students construct concept maps, they often find new meanings and new relationships for the concepts that they already possess. To drive home the point, Novak argues that as society moves farther away from a model of institutional help to one of self help, there is an increased need for schooling that focuses on meaningful learning, which empowers students to take charge of their lives and make good decisions.

Novak and Gowin (1984) determined that concept maps were particularly useful pre-instructional tools with students for four reasons. First, concept maps force students to carefully choose concept labels as the basis for the maps. Second, the maps make students keep searching their cognitive structures for relevant concepts. Third, concept maps force students to organise their thoughts into hierarchies and to consider the relationship between concepts in order to choose good linking words that further organise their conceptualizations. Fourth, concept maps help students to, "discriminate between specific objects or events and the more inclusive concepts those events or objects represent" (pp. 41,42). Further, Novak and Gowin (1984) found that concept maps can then be used as a post-instructional tool in order to show how much students have, "elaborated, refined, and cross-related concepts in their own cognitive structures" (p. 42).

Rebich and Gautier (2005) found that concept mapping is a useful tool for assessing changes in scientific knowledge for six reasons:

- concept maps allow an examiner to explore student knowledge at a higher level of complexity than traditional assessment methods, such as paper-and-pencil tests,
- the examiner does not assume that all students have mastered exactly the same material,
- concept maps can reduce test anxiety because they are perceived as being more of a hands-on activity that resembles nothing more than note-taking, a regular classroom activity,
- concept maps are more efficient than interviews because they require less time to gather the measurement data,
- assessing learners using concept maps is a non-linear activity, as opposed to writing assignments which are fairly linear, and
- pre- and post-instruction concept maps allow the examinee a chance for metacognitive reflection.

Lim et al. (2009) warn that “learners’ cognitive capability should be considered a critical factor affecting the effectiveness of concept-mapping strategy use” (p. 608). Their study compared the effectiveness on learning of three levels of generativity of concept maps: fully learner-generated, where learners started with a blank slate; partially learner-generated, which is basically a fill-in-the-blank exercise with many of the concepts provided; and expert-generated where the learners were given the completed concept map and shown how it relates concepts into propositions. The study also looked at the effect of the level of self-regulated learning each student had on knowledge formation. Lim et al. (2009) made three important conclusions from their research. First, fully learner-generated concept maps were more effective on knowledge acquisition than expert-generated concept maps. Second, learners who used partially learner-generated concept maps were no more successful at knowledge acquisition than learners who used expert-generated concept maps. Third, learners' self-regulated learning skills were a critical factor for knowledge acquisition. Overall, results showed that learners acquire knowledge most effectively when they possess high self-regulated learning skills and they produce their own concept maps. An unexpected result was that partially learner-generated concept maps did not help learners with low self-regulated learning skills. These concept maps were supposed to help a student possessing this level of self-regulated learning skills because it reduces the cognitive load of the exercise.

In the study conducted by Rebich and Gauthier (2005), students were asked to create pre-and post-treatment concept maps of their knowledge surrounding the concept of global warming. The treatment in their case was the instruction that students received during one term in a class devoted to the topic of global climate change. For each concept mapping exercise, students were provided with guiding questions. Their analysis used a visualizing method to examine the structure of the maps, the inter-connectedness of the concepts and propositions, and the content where most learning occurred. They began their analysis by defining concepts that students included in their concept maps as being exact, near, or other. Next, propositions were defined as useful, examples, weak, or misconceptions. Once this was done, the researchers evaluated changes in the numbers of concepts, useful propositions, and the ratio of links to concepts. Increases in the number of exact or near concepts and the number of useful propositions, coupled with a lower links-to-concepts ratio, which indicated more differentiation of knowledge, and a decrease in the number of misconceptions related that the learners had gained new understanding of the knowledge domain of global warming. The results showed that overall, numbers of concepts and propositions increased after instruction, and a number of misconceptions had been weakened, causing the researchers to conclude that “Concept mapping proved to be a valuable assessment tool that allowed us to observe significant increases in the breadth and interconnectedness of the student knowledge” (Rebich & Gautier, 2005, p. 364).

Ruiz-Primo and Shavelson (1996) characterize concept map assessments as having three components: a task, a response form, and a scoring system. These three components can be as simple or as complex as required, depending on the purpose of the assessment. The task is simply what the person being assessed is expected to accomplish: “Construct a concept map of the knowledge domain special relativity”, or “List all of the concepts that would be used when describing the knowledge domain Baroque Music”. The response form relates both the type of response that is expected from the person being assessed and what mode they are being assessed in. For example, for the first task above, the examinee may be asked to construct the concept map on an 11 by 17 piece of white paper using a pencil. For the second task, the examinee might be asked to list the concepts in an email and send them to a teacher to be scored. In this research, the task and the response form are, respectively, to construct a concept map of projectile motion while using simulations (task) on letter-sized pieces of blank paper using specific colours of ink (response form). While these first two components of concept map assessment are fairly straight-forward, the third component, scoring systems, has been investigated extensively, and many variations exist. The next section describes scoring systems that can be used to determine whether real, meaningful conceptual change has occurred or not.

2.2.2 Concept Map Scoring

Several scoring systems have been developed in order to evaluate student concept maps. They range from rubrics that rate and count the appropriateness of propositions and their hierarchical arrangement (Novak, 1998; Novak & Gowin, 1984), to a combination of three scores based on ratios of correct propositions (Ruiz-Primo & Shavelson, 1996), to a system that awards a point for each concept and correct proposition, and consecutively higher points for propositions located farther from the first level of the hierarchy, which was proposed by Bayram (1995), as cited in Besterfield-Sacre, Gerchak, Lyons, Shuman, and Wolfe (2004). Two other approaches use generalizability theory (Yin & Shavelson, 2008) and the use of a holistic rubric (Besterfield-Sacre, et al., 2004).

Two scoring systems were considered for use with this research based on their simplicity of use and their reliability (the possibility of the consistency of scores given). The first is the system proposed by Novak and Gowin (1984), and the other is the holistic rubric proposed by Besterfield-Sacre et al. (2004). Novak and Gowin’s scoring system assigns points weighted for four different categories, with an additional option of determining the student’s performance compared to a “criterion map”. This system will be presented in detail in the next chapter. The scoring system proposed by Besterfield-Sacre et al. (2004) is more holistic in nature and it uses a three-point scale to assess three criteria of each concept map: comprehensiveness, organization, and correctness. The rubric is shown in Table 2.

Table 2

Holistic Concept Map Rubric (Besterfield-Sacre, et al., 2004, p. 113)

	1	2	3
Comprehensiveness – covering completely/broadly	The map lacks subject definition; the knowledge is very simple and/or limited. Limited breadth of concepts (i.e. minimal coverage of coursework, little or no mention of employment, and/or lifelong learning). The map barely covers some of the qualities of the subject area.	The map has adequate subject definition but knowledge is limited in some areas (i.e., much of the coursework is mentioned but one of two of the main aspects are missing). Map suggests a somewhat narrow understanding of the subject matter.	The map completely defines the subject area. The content lacks no more than one extension area (i.e., most of the relevant extension areas including lifelong learning, employment, people, etc. are mentioned).
Organization – to arrange by systematic planning an united effort	The map is arranged with concepts only linearly connected. There are few (or no) connections within/between the branches. Concepts are not well integrated.	The map has adequate organization with some within/between branch connections. Some, but not complete, integration of branches is apparent. A few [cross-links] may exist.	The map is well organized with concept integration and the use of [cross-links]. Sophisticated branch structure and connectivity.
Correctness – conforming to or agreeing with fact, logic, or known truth	The map is naive and contains misconceptions about the subject area; inappropriate words or terms are used. The map documents an inaccurate understanding of certain subject matter.	The map has few subject matter inaccuracies; most links are correct. There may be a few spelling and grammatical errors.	The map integrates concepts properly and reflects an accurate understanding of subject matter meaning little or no misconceptions, spelling/grammatical errors.

The study conducted by Besterfield-Sacre et al. (2004) compared the efficacy of using an analytic scoring system similar to the one proposed by Novak and Gowin (1984) to the holistic one described above and found that the holistic system gave more robust and reliable results. However, the analytic system they used did not limit the scoring of propositions to those that were actually valid: all were scored. Although this was a weakness in their method, it doesn't weaken their holistic scoring method, and there was still merit in considering it for this study.

Why use concept maps for the purpose of this study? A fundamental benefit of using concept maps to illustrate cognitive structure is that they can be used as a pre-treatment tool to gather an understanding of a learner's pre-treatment conceptual understanding of a knowledge domain, and then as a post-treatment tool to determine whether conceptual change has taken place during the treatment. It follows that concept mapping provides an assessment tool to measure cognitive changes in learners and to see how their conceptual understanding has changed.

2.3 Simulation Design Principles

Educational simulations are relatively recent additions to the classroom (Adams, et al., 2008a), yet with the ubiquity of computers in our society and the ability to access the web from any classroom in Alberta, web simulations are a tool that educators can not overlook. Simulations may allow teachers to facilitate student-centred lessons that allow students to conduct activities that are too expensive or too dangerous to conduct in real-life, and the students have the ability to do repeated trials. However, simulations used in the classroom need to be designed according to some guiding principles, and the purpose of this section is to present a summary of those principles that the research community currently espouses. The literature regarding design principles for simulations seems to centre around three areas with the goal of effectively combining learning theory, pedagogy, software engineering and video game design (Kali & Linn, 2008; Mor & Winters, 2007). These three areas guiding the research are: engagement, coherence, and consistency.

2.3.1 Engagement

When students are engaged, they actively seek answers and investigate and explore features of simulations by manipulating and interacting with controls (Adams, et al., 2008a), and they tend to report the experience as being enjoyable, interesting, and motivating (Kim, et al., 2007; Wishart, 1990). Engagement, and its related term motivation, in the case of simulations is the condition or state that learners experience that causes them to be interested in beginning, persevering with, or delving further into, a simulation. Motivation can be extrinsic or intrinsic (Adams, et al., 2008a; Sardone & Devlin-Scherer, 2010). Adams et al. (2008a) suggest that, much of the time, teachers "primarily provide the scaffolding and goals for the simulation use" (p. 12), suggesting that it may be the case that extrinsic motivation is quite common for current uses of simulations in classrooms. However, simulations that promote engagement due to intrinsic factors may be far more effective than those where extrinsic factors are the motivation (Kim, et al., 2007; Pol, Harskamp, & Suhre, 2005; Sanford, 2008; Trindade, Fiolhais, & Almeida, 2002; Wishart, 1990).

Malone (1981) suggests that learning environments are intrinsically motivating when they have three characteristics: challenge, fantasy, and curiosity. With respect to challenge, Malone proposes that there are four different aspects of challenge within an intrinsically motivating learning environment. First, there must be a set of clearly defined and meaningful goals, and it must provide concrete feedback to the user. Second, there must be uncertain outcomes for the user because "an environment is not challenging if the person is either certain to reach the goal or certain not to reach the goal" (p. 358). Third, to make an instructional environment challenging and intrinsically motivating, the designer has to make some choices regarding, "toys versus tools" (p. 359). The design principles for toys and tools are almost exactly opposite. Toys are meant to promote motivation and engagement because they add enjoyment for the user. However, they should be difficult to use in order to increase the challenge: the user wants to use the toy so he or she is motivated to overcome difficulties learning how to use it. Tools, conversely, should intentionally be designed to be easy to use so that the challenge is in reaching an outcome, not in using the tool. Finally, an element of challenge is related to self-esteem. Success at accomplishing a task increases self-esteem, while failure decreases it. When considering challenge with regard to a learning environment, the designer must make the environment challenging enough to keep interest, but not so challenging as to promote failure. One of the ways of doing this is to allow for variable difficulty levels, or to allow the user to choose an appropriate difficulty level for his or her ability. In later research, Wishart (1990) found that the challenge of a game or simulation, and motivation, could be increased by providing a high score table. The second characteristic that Malone (1981) suggests leads to the design of intrinsically motivating learning environments is fantasy. In this case, fantasy simply means that the learning environment allows the user to produce mental images that are not currently present to the senses, nor might they ever be. Fantasy in a learning environment can mean anything from pretending to slay a dragon to throwing darts at balloons at the midway of a fair. Malone premises that there are two types of fantasy, and one is more effective than the other. Extrinsic fantasies are those "where the fantasy depends on the use of the skill but not vice versa" (Malone, 1981, p. 360). For example, if a user can advance a racehorse around a track by answering arithmetic questions, this would be considered an extrinsic fantasy: arithmetic is necessary to cause the horse to go around the track, but horse racing is not a necessary set of skills in order to do arithmetic. Intrinsic fantasies are those where "not only does the fantasy depend on the skill, the skill also depends on the fantasy" (Malone, 1981, p. 361). An excellent example of this is the set of projectile motion simulations being used for this research. In order to hit targets with projectiles, one must know how to set the initial angles and velocities. Firing the projectiles, the fantasies in this case, at a target or to investigate an effect depend on an understanding of physics skills and knowledge, while physics skills and knowledge, particular to this case, depend on the idea of projectiles. The third characteristic of intrinsically motivating learning environments has to do with curiosity. In Malone's (1981) words:

> …environments should be neither too complicated nor too simple with respect to the learner's knowledge. They should be *novel* and *surprising*, but not completely incomprehensible. In general, an optimally complex environment will be one where the learner knows enough to have expectations about what will happen, but where these expectations are sometimes unmet (p. 362).

This characteristic of curiosity can be evoked to motivate students in two different ways (Kim, et al., 2007; Malone, 1981). Sensory curiosity, similar to the term emotional interest in the literature, occurs when stimuli cause an arousal response within the learner. Cognitive curiosity, or cognitive interest, is "produced by the relationships between incoming information and background knowledge" (Kim, et al., 2007, p. 261). These two types of curiosity, sensory and cognitive, can be related to Posner et al.'s (1982) model of conceptual change. If stimuli in a simulation provoke only an arousal response, it is likely that the only demand on the user is to use existing concepts to cope with the situation; assimilation is taking place. If the stimuli require the user to relate new information with existing concepts, both assimilation and accommodation are possible. It seems that these two types of curiosity may occur at the same time on some occasions. A user may experience not only an arousal response, evoking a desire in the user to continue further with the simulation, but also a disconnect between existing concepts and the phenomenon being simulated. If the disconnect can be resolved using existing concepts, assimilation will take place. However, if the user cannot explain the phenomenon using existing knowledge, there is need for accommodation. If the cognitive curiosity is coupled with sensory curiosity in this case, the user may be motivated to continue using the simulation in an attempt to accommodate the new conception.

Some of the software applications that are being integrated into classroom lessons and libraries are pre-existing video games because of their ability to influence the development of cognitive and social skills (Ang, et al., 2008; Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Sanford, 2008; Sardone & Devlin-Scherer, 2010). A current example of this is the use of the smartphone game "Angry Birds" to investigate physics principles (Crecente, 2011). The game incorporates projectile motion and momentum concepts and obeys many laws of physics, but the natural constants associated with the laws, like the acceleration due to gravity on Earth, are adjusted away from real-life values in order to make the game seem realistic within its scale. Teachers are asking students to analyse the game environment the same way they would investigate the physical laws of their surroundings: calculate the acceleration due to gravity in the game, and determine if the game obeys conservation laws. Sardone and Devlin-Scherer (2010) studied the ability of educational video games to promote motivation and the fostering of 21st century skills, especially critical thinking, problem solving, creativity, and collaboration. They made two conclusions. First, digital games are able to motivate students and promote the development of 21st century skills when the games are selected by a highly technology-proficient faculty member. This qualification regarding the selection of the games led to a second conclusion, that current teacher training programs, and recently past training programs, have not adequately prepared teachers for technology-rich environments. Therefore, teachers should be paired with an educational technology colleague in order to make wise decisions about choosing digital resources that can be used in their classrooms to foster the development of 21st century skills in students.

While the findings of Sardone and Devlin-Scherer (2010) are important, and they provide a very rich literature review of what is being found related to the considerations of the design of educational video games, these games are very different from simulations.

Juul (2003), as cited in Ang, Avni, and Zaphiris (2008), defines a game as:

> ...a rule-based formal system with a variable and quantifiable outcome, where different outcomes are assigned different values, a player exerts effort in order to

> influence the outcome, the player feels attached to the outcome, and the consequences of the activity are optional and negotiable (p. 534).

The important part of this definition is that the "player exerts effort in order to influence the outcome". This comes with the understanding that the designer must provide some sort of motivation for the player, whether it is entertainment, reward, or punishment. As well, the designer must make the player become "attached to the outcome", meaning that the designer must make the outcomes desirable to players. It is clear that the purpose of the game is to entertain the player, and motivate the player to the point that he or she feels driven to reach the outcome. Video games satisfy Malone’s (1981) characteristics of an intrinsically motivating environment.

Simulations, on the other hand, are meant to display real-life phenomena and allow users to experience those phenomena in ways that they may not be able to in real life. The outcome is not necessarily to win, although components of the simulation may be game-like. As such, elements of intrinsically motivating learning environments may need to be built-in as a side benefit to cause the user to want to begin, and to continue, interacting with the simulation.

Adams et al. (2008a) found that "students engage in exploration and sense making only *after* they begin to interact with the simulation" (p. 406), and little educational value is derived from animations where interactivity is limited (Kali & Linn, 2008; Tversky, Morrison, & Betrancourt, 2002). This suggests that simulations that simply act as demonstrations have little value as learning environments for students, without the intervention of teachers, and interactivity is a necessity for learning to take place. When considering the interactivity of the simulation, the designer should consider a variety of options. First, motion is an important motivator: “Interviews show that anything in motion draws the student’s attention first; but, if the simulation simply demonstrates the motion of an object, students rarely develop new ideas or insights” (Adams, et al., 2008a, p. 405). The designer also needs to make choices regarding which of the related parameters should be manipulated, and what sorts of controls should be included. This is especially important when one is considering whether a user should be able to investigate those parameters that do not have an effect on a particular phenomenon. This also means that the designer should decide whether to disable controls for certain situations. This decision to disable controls needs to be made based on educational reasons, and not just for the ease of coding or appearance. In keeping with the idea of Malone's (1981) intrinsically motivating learning environments, the idea of curiosity may guide some of these decisions. Adams et al. (2008a) discovered that "students quite often encounter a word in the simulation that they don't know. Typically when this happens, students play with the control labelled with the unknown word and subsequently create a working definition for the word" (p. 408). In order to keep users actively engaged, exploration is essential. However, features of simulations that encourage exploration and student thought that are not productive are flaws (Adams, et al., 2008a), and may have a negative impact on learning as “seductive details” (Kim, et al., 2007). Another aspect of simulations that Adams et al. (2008a) found was important for students to be engaged was that the simulations should be fun, and when individuals are offered choice in how to use a simulation, there can be increased enjoyment, performance, and persistence (Kim, et al., 2007). Kim et al. found that choice, extended to controllability, promoted interest and motivation. However, "every feature adds to a student's cognitive load and so needs to have educational purpose", and, "features can be so much fun to play with that students are distracted from learning" (Adams, et al., 2008a, p. 409). Fun can be stimulated by what Adams et al. (2008a) termed little puzzles, which are clues in the simulation that encourage the user to form questions and explore new parts of the simulation. These little puzzles can be formed by limiting the amount of legends and labels, which are often unfamiliar terms to users, in order to encourage the development of working definitions as described above. For example, in one of the simulations used in this research, the designers allowed users to manipulate drag coefficient and projectile diameter while investigating the effects of air resistance on projectiles. However, there are no definitions or explanations given for these terms, so if a student wanted to determine their meanings, he or she would have to form working definitions based on manipulating the variables and observing the resulting effects on the projectiles.

Colour and platform are also important considerations:

> …we hypothesize that the bright colors, 3-D look of the controls, and simple cartoon-like features are what attract users to the Flash simulations. Too crude and simplistic graphics, or an overly complex appearance, are both perceived as less fun. We've seen a positive response to subsequent Java simulations that incorporate many of the same characteristics of the Flash simulations, supporting our hypothesis (Adams, et al., 2008a, pp. 409-410).

Lowe (2004) suggests that colour should be used with discretion because elements that are contrasted are noticed more, such that users “preferentially extracted perceptually conspicuous information while neglecting more subtle yet thematically relevant aspects of the [simulation]” (p. 260), thus affecting learning results. This need for discretion is illustrated well by an example provided by Kali and Linn (2008). Students using a simulation showing conduction of heat got the impression that heat in a metal bar was red and the absence of heat was blue based on colours chosen by the designers of the simulation.

Subsequent to their earlier study, Adams et al. (2008b) found that "if simulation controls are difficult to master, students’ attention is focused on the use of the simulation rather than on the exploration of scientific concepts" (p. 555). This same group also found that the most intuitive controls in simulations use the mouse as an extension of the user's hand. Examples of this are click-and-drag objects, grabbable objects, sliders, and radio buttons. However, the same research found that checkboxes could have a detrimental effect such that users would often select them, but neglect to turn them off later. In fact, the researchers found that once a checkbox was selected, it was very seldom unchecked later during exploration.

Finally, the level of feedback provided to users should be considered as a factor of engagement (Granlund, Berglund, & Eriksson, 2000) such that an optimal level of complexity is achieved that satisfies the user’s needs to continue while remaining consistent with both the user’s “repertoire of ideas and the nature of the visualization” (Kali & Linn, 2008, p. 185).

Some of the reasons why users do not engage with simulations include the following: they have not had enough time to work with the simulation; they have difficulties understanding how to use the simulation; the simulation is too complex and overwhelms the users, such that they don't know where to start (Kali & Linn, 2008); and the user believes that they already understand the content that is being simulated, and so they see the simulation as a demonstration tool (Adams, et al., 2008a). This last reason why users do not engage with simulations is an important finding. Adams et al. (2008a) found that students who believe they already know the content presented in the simulation will use the simulation less effectively. Adams et al. termed this entering the "performance mode", and found that, "the more the students believe they know, the less they engage with the simulation and the greater they become tense and frustrated when asked questions they don't quite understand" (p. 414).

The characteristics described in this section (challenge, fantasy, curiosity, motion, choice, fun, colour, feedback, and intuitive controls) make up the list of what I have termed engaging characteristics that will be compared with engagement evidence in order to discuss the second research question.

2.3.2 Coherence

The previous section on engagement dealt with factors related to, and attributes of, simulations that affect interest and interactivity. The following section describes coherence, and a definition is a necessary introduction.

Following the *coherence principle* when designing educational simulations simply means that the designer emphasizes “the importance of having all elements (controls and visual cues) directly related to the learning goals of the simulation and excluding extraneous information" (Adams, et al., 2008a, p. 416). Clark and Mayer (2003), the originators of the coherence principle, found that many of the simulations available to educators today “use a wide variety of appearances, controls, graphics, interactivity, and design principles, often guided only the designers’ preferences or ease of coding” (p. 2). Clark and Mayer (2003) suggest that there are three ways that extraneous information affects learning. First, extraneous information can distract the learner away from the relevant material. Second, extraneous information can disrupt and prevent the learner from making appropriate links between relevant material, because irrelevant material gets in the way. Third, extraneous information can seduce the learner into organizing new and relevant material in inappropriate ways through the lens of inappropriate existing knowledge. In summary, the coherence principle simply reminds designers that the material that is presented in a simulation needs to be relevant and appropriate to the learning outcomes particular to the context presented in the simulation, and any extraneous information should either be excluded from the simulation, or be included with caution. Many simulations may not improve learning because they overload learners (Tversky, et al., 2002), and simulations are most effective when teachers are aware of the design used and receive guidance from the designers (Kali & Linn, 2008).

In order to increase coherence and to help teachers and designers incorporate simulations in curricular materials, Kali and Linn (2008) propose four principles. First, the visual complexity of simulations should be reduced to help learners identify what information is important and to avoid having those learners becoming distracted from the main learning outcomes of the simulation. This principle of keeping the interface of the simulation focussed and simple is supported by Lowe (2004) who found that learners tend to investigate one function at a time and form superficial meanings rather than interconnected meanings; a complex interface would likely distract learners as they navigate the simulation function-by-function. Second, scaffolding the process of generating explanations makes the thinking behind the simulation visible, allowing students to form meaning. Third, the modeling of complex thinking by the student should be supported such that the students "can create their own models of a phenomenon, [and] make decisions about how different elements of the phenomenon relate to each other" (Kali & Linn, 2008, p. 189). Finally, simulations should allow for the use of multiple linked representations rather than one, linear representation that must be followed from start to finish. Kali and Linn (2008) propose that when these principles are made visible to teachers, their students experience a maximized benefit from a simulation.

Three other concepts are related to the coherence of a simulation. These are the concepts of breaking, exaggerations, and misconception testing. Adams et al. (2008b) found that simulations need to break when pushed to extremes in order to simulate real life. For example, in a simulation that mimics the use of an electrical circuit, if a user applies too much current to a circuit containing a light bulb, the bulb must burn out. However, a balance has to be found between allowing a simulation to break, and causing the user to become distracted by figuring out ways to make the simulation break as a form of entertainment, thus detracting from the learning goals. Adam et al. (2008b) discussed a simulation which simulated bodies rolling down a ramp, and when the friction on the ramp became too great in some circumstances, the simulation displayed a fire. The designers of the simulation programmed a firehouse dog to come out and put out the fire. Each time the fire started, a different dog character came out put out the fire. The researchers found that users intentionally tried to start fires in order to see how many different dogs they could make appear on the screen. This problem was solved by programming only one dog character. Exaggerations are an important part of those simulations that mimic phenomena that are difficult to see. These exaggerations are often cartoon-like features. Adams et al. (2008b) suggest that careful consideration regarding the cognitive maturity of the users must be exercised when using exaggerations, and illustrate this using an electrical circuit simulation. In early iterations of a circuit used with young science students, simulating electrons as small blue spheres was very helpful for students in order to visualize the concept of current. However, due to a problem with programming, when the circuit was interrupted, the "electrons" tended to bunch up near switches and loads. Participants tried to incorporate this into their learning by trying to rectify why there was a change in electron density near switches and loads. While older students may understand the necessity of this exaggeration, younger students may see the exaggeration as fact. For example, using the example above, younger students, or those students with less science experience or of lower cognitive maturity, may form the misconception that electrons are visible spheres that move through wires. Adams et al. (2008b) found that it is sometimes useful to allow students to explore misconceptions by constructing controls that don’t affect the phenomenon being tested. Care should be taken that the mere presence of the control doesn’t suggest to the user that the parameter being controlled does, in fact, have an effect if the user doesn’t use the control during simulation.

2.3.3 Consistency

The concept of consistency is one that would be difficult to maintain given the number of different people designing educational simulations. Adams et al. (2008b) found that users are able to engage with a simulation much quicker, and use it much more effectively and with greater satisfaction, if the controls of the simulation are similar to the controls of simulations that they've used in prior experiences.

The research of Adam et al. (2008b) arrived at two critical conclusions regarding the consistent organization of a simulation. First, there should to be a control panel section guided by the principle that the maximum number of controls should be three groups of three controls in each. If the simulation has more controls than this, users tend to hesitate before investigating the simulation. These controls should follow the rule that they should be extensions of the hand as much as possible, and they should have very limited amount of text associated with them. Second, there needs to be a play area that is completely separate from the control panel section. This is the area where all of the animations are carried out. As much as possible, the objects in the play area should be grabbable, and not too numerous. As well, there should be very little, or no, text:

> The play area contains the physical objects that the user is investigating. We find that students always begin by attempting to manipulate these objects before turning to the control panel. For this reason, it is best to allow manipulation of the play area objects directly with the mouse as much as possible (Adams, et al., 2008b, p. 570).

2.4 Summary

In this chapter, I presented a review of the literature pertinent to this research. In the first section, I presented an overview of constructivism and conceptual change models. Simulations may serve a role in lessons that incorporate constructivist methodologies, and if teachers have an understanding of the mechanisms by which students experience conceptual change, they may be able to incorporate simulations into lessons in such a way as to promote conceptual change in students. In the second section, I presented an overview of the construction and scoring of concept maps. This is pertinent because this method may be used to show conceptual change in students in both qualitative and quantitative ways. Finally, in the last section, I presented the principles in the literature for simulation design. Since the secondary research question attempts to determine whether simulations with engaging characteristics seem to promote conceptual change in students, the final section serves as benchmark from which to evaluate the three simulations used in this research.

CHAPTER 3: METHOD

This research is based on a small-sample, triangulation mixed methods design (Creswell, 2005). In this type of research, both quantitative and qualitative data are collected either simultaneously or close to it, and they are used together to argue a thesis or theses. This is different from other mixed methods designs where the two forms of data are collected at different times and/or from different samples in such a way so that one set of data is used to explore the other set of data, or one set is used to explain or confirm the other set of data. In this chapter, I will describe the participants in the research, the data collected, the process used to collect the data, and the simulations that the participants interacted with.

3.1 Description of the Participants

This research involved six students to explore the effect that using simulations has on learning. Specifically, the learning outcomes central to this research were taken from the Alberta Physics 20 Program of Studies related to Unit A: Kinematics. The general outcome from the Program of Studies (2007) that was investigated is, “Students will describe motion in terms of displacement, velocity, acceleration and time” (p. 20). The specific outcomes that relate to this research come from four different areas of the program of studies and are classified and stated as follows:

- Knowledge Outcome (20 – A1.5k): *Students will* explain, quantitatively, two-dimensional motion in a horizontal or vertical plane, using vector components. (p. 20),

- Skill Outcome (20 – A1.3s): Students will analyze data and apply mathematical and conceptual models to develop and assess possible solutions (p. 21),
    - solve, quantitatively, projectile motion problems near Earth's surface, ignoring air resistance,
- Nature of Science Outcome (AI – NS3): Students will estimate and calculate the value of variables, compare theoretical and empirical values, and account for discrepancies (p. 8), and
- Information and Communication Technology Outcome (ICT C6 – 4.1): Students will use technology to investigate and/or solve problems, and investigate and solve problems of prediction, calculation and inference (p. 11).

The students chosen for this study had completed Science 10, but at the time of data collection had not yet had instruction related to the projectile motion outcomes mentioned above. The students should have been familiar with basic kinematics and simple conservation of energy contexts. The participants in the study, four males and two females, were all grade 10 students from a high school in a large town in central western Alberta.

Students were recruited to participate in the study based on recommendations from their teacher, who was chosen based on convenience. I chose to use a convenience sample because I know a number of physics teachers through my profession, and I approached a few of them about the possibility of having their students participate in this research. One teacher in one school was able to provide a small class of students from whom to recruit, meaning the research could be done at one location over two visits, hence the convenience sample. The students attended a short meeting where I presented an overview of the study, and they were given consent forms (for their parents to read and sign), assent forms (for them to read and sign), and information sheets that outlined the research in a one-page format. Once the students submitted their assent forms and their parents submitted their consent forms, they were able to participate.

3.2 Step-wise Participant Experience

Each participant was asked to construct a concept map before using the simulations to demonstrate his or her existing pre-conceptions regarding projectile motion, and then to modify that map once he or she finished using each simulation to demonstrate whether conceptual change had occurred. This required some instruction on how to draw a concept map, and so the participants were presented with Figure 6 and I explained the basic components and organization of a concept map to them.

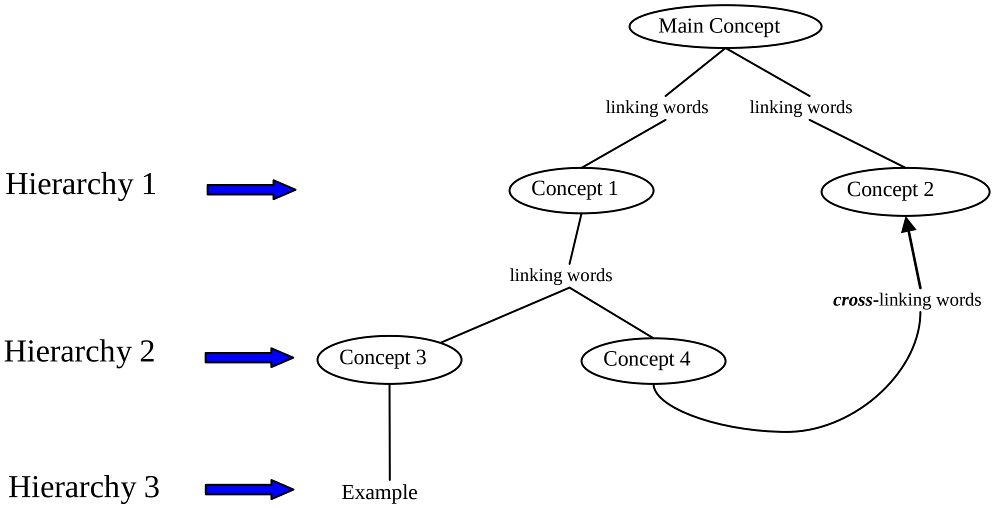


Figure 6. The general components of a concept map.

This general concept map contained all of the components of concept maps that the participants needed to know: concepts, linking words, examples, cross-links, hierarchies, and the formation of propositions.

Once each participant was familiar with the general components and structure of a concept map, I presented a concept map of "A School" to them that I had constructed, shown in Figure 7.

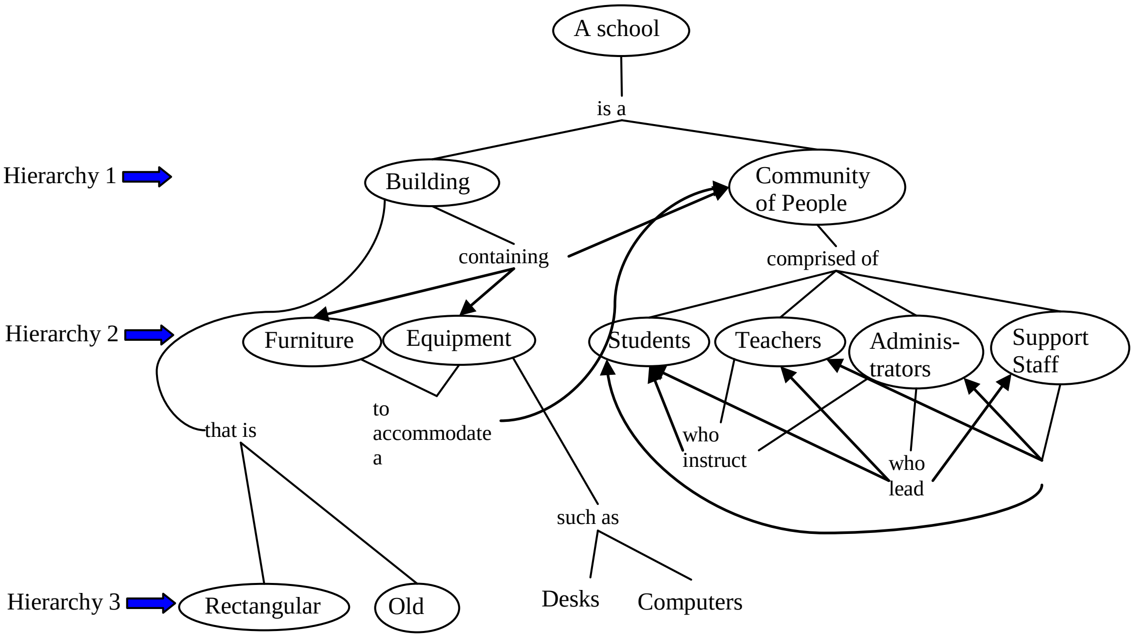


Figure 7. A concept map of "A School" knowledge domain.

The concept map shown above was discussed, especially the flow of the concepts and linking words that make propositions. From Figure 7, it can be shown that, "**A school** *is a* **building** *containing* **equipment** *to accommodate a* **community of people** *comprised of* **administrators** *who lead* **teachers** *who instruct* **students**". Participants were shown the hierarchical structure of the concept map, the examples given, and the cross-links present.

Finally, as a check to test readiness for concept-mapping, each participant was asked if they could think of any possible improvements to the concept map.

In the final instructional step for concept mapping, the participants and I constructed a concept map of the knowledge domain "Solar System" together. This knowledge domain was chosen because there are outcomes in the Alberta science curricula throughout the elementary school (up to grade 6) and junior high school (through grade 9) programs of study that cover various aspects of the components and workings of the solar system: it is a knowledge domain that all Alberta science students of the participants' age should have some familiarity with. In this way, they had the opportunity to become accustomed to concept mapping a science domain using science concepts and, possibly, scientific linking words.

Each participant was then asked to individually construct a pre-treatment concept map of the "Projectile Motion" domain of knowledge using a pencil. This entire concept mapping instruction and construction took place during one visit to the school. Once the participants were finished drawing their projectile motion pre-treatment concept maps, I left the school and prepared for the second visit.

On the second visit to the school, participants completed their participation in the study by accessing web-based simulations and then responding to a short interview. Each student was allowed to access three projectile motion simulations at the following URLs: Simulation I at http://galileoandeinstein.physics.virginia.edu/more_stuff/Applets/ProjectileMotion/jarapplet.html, Simulation II at http://phet.colorado.edu/en/simulation/projectile-motion, and Simulation III at http://www.physicslesson.com/phe/projectile.htm. It should be noted that the site of the last simulation has been moved to the designer's website at http://www.walter-fendt.de/ph14e/projectile.htm since the data was collected. Each participant was allowed to access each simulation for as much time as they needed in order to conduct two activities. First, each participant was asked to alter his or her concept map using a coloured pen associated with a particular simulation. This was used to show any conceptual changes that the simulation possibly facilitated. Second, the participant's monitor was videotaped, allowing me to collect data related to the actions the participants performed on the simulations, any repetitive activities undertaken by the participants, and the times spent using particular functions of the simulation. The simulations were presented in different orders to each participant to ensure that learning wasn't affected by the order of presentation. For example, since participants had not been taught this particular concept, it may have been that the exposure to the first simulation would have caused the most changes to the concept maps. As well as their concept maps, participants also had access to a calculator and blank paper so that they could do calculations or record data. Once each participant had finished accessing the simulations and modifying his or her concept map, he or she was asked to produce a final copy of the concept map. Finally, each participant responded orally to a fourteen-question, scripted interview. Those questions are provided in Appendix A.

In summary,

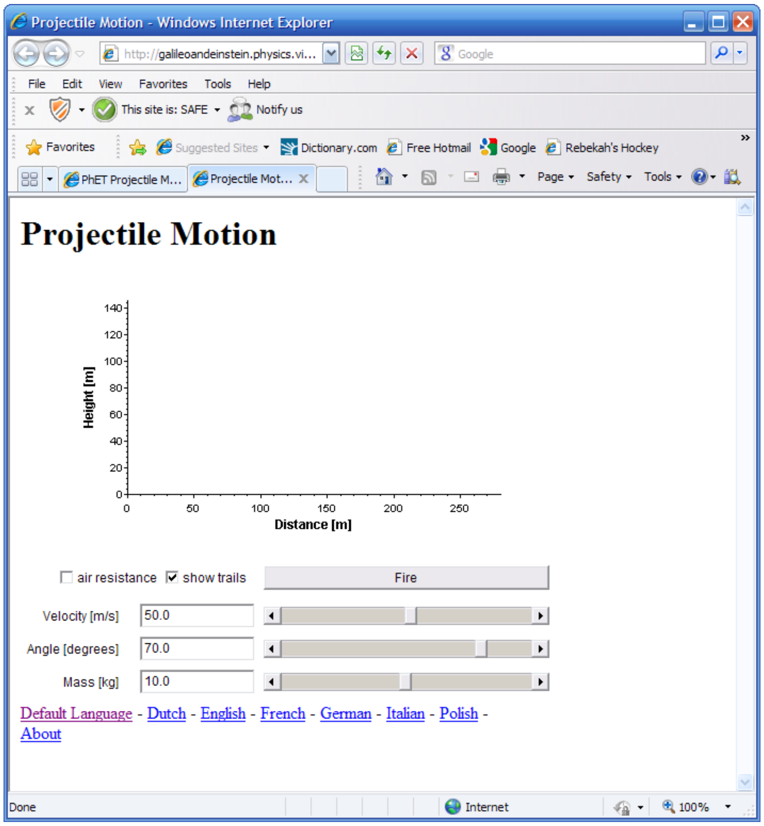
1. Participants were taught how to construct a concept map.
2. Each participant was allowed to construct a pre-treatment concept map for the projectile motion knowledge domain in pencil.
3. Participants accessed the three projectile motion simulations.

4. Participants' computer monitors were videotaped.
5. Participants altered their pre-treatment concept maps during their use of the simulations using different coloured pens corresponding to the particular simulations.
6. Participants produced final versions of their concept maps.
7. Each participant was asked to respond to scripted questions during an interview.

3.3 Descriptions of the Simulations Used

The three simulations used in this research were selected because they have very different characteristics. In summary, one simulation has a basic appearance and functionality, another is game-like, and the third has a great deal of functionality. In this section, I will present the reasons why I chose these three simulations for this research along with descriptions of the simulations.

Screenshots of the initial views of the simulations are shown in Figures 8, 9, and 10.



Projectile Motion

☐ air resistance ☑ show trails

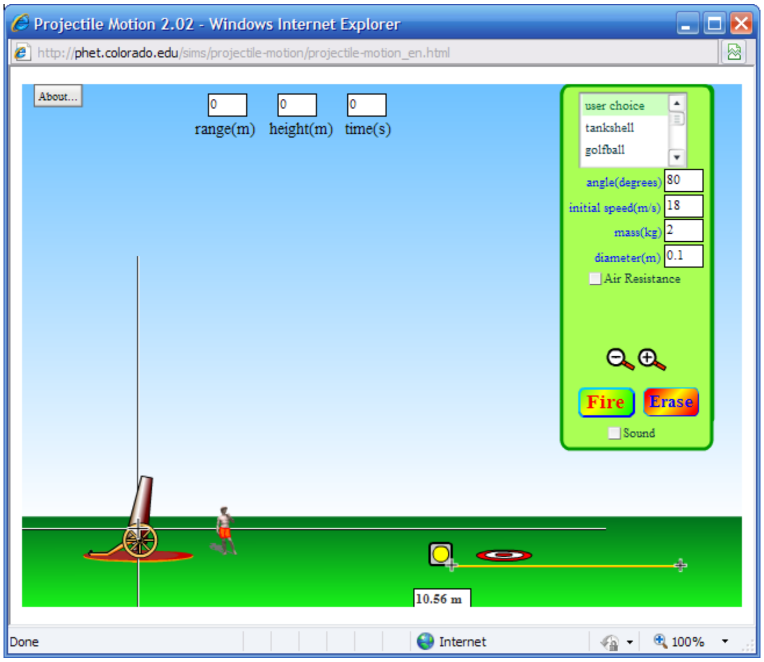
Velocity [m/s] 50.0

Angle [degrees] 70.0

Mass [kg] 10.0

Default Language - Dutch - English - French - German - Italian - Polish -
About

Figure 8. Screen Shot of the initial view of Simulation I.



range(m) 0

height(m) 0

time(s) 0

angle(degrees) 80

initial speed(m/s) 18

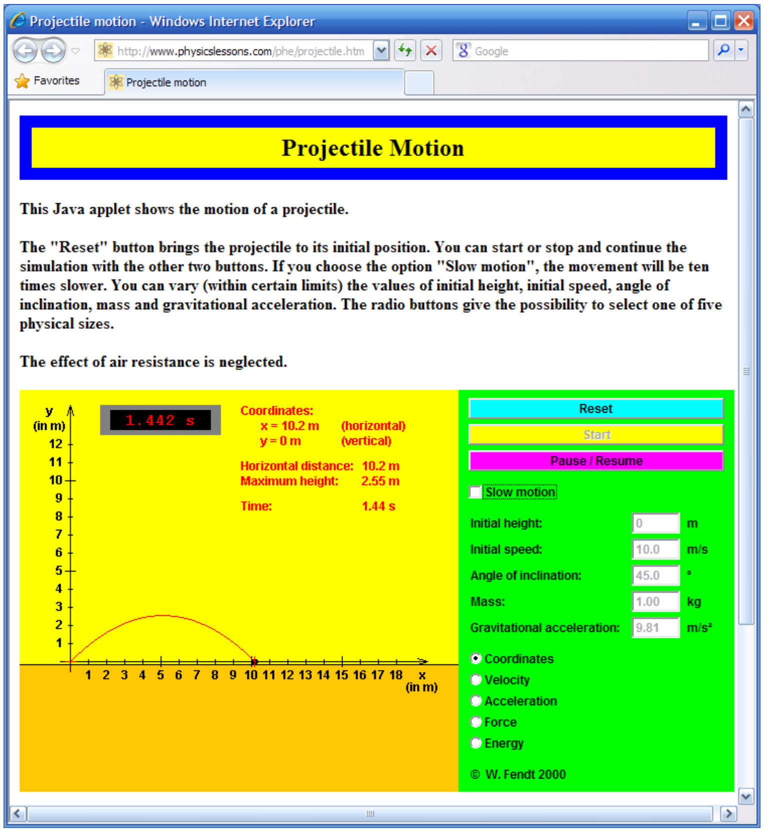
mass(kg) 2

diameter(m) 0.1

☐ Air Resistance

☐ Sound

Figure 9. Screen Shot of the initial view of Simulation II.



Projectile Motion

This Java applet shows the motion of a projectile.

The "Reset" button brings the projectile to its initial position. You can start or stop and continue the simulation with the other two buttons. If you choose the option "Slow motion", the movement will be ten times slower. You can vary (within certain limits) the values of initial height, initial speed, angle of inclination, mass and gravitational acceleration. The radio buttons give the possibility to select one of five physical sizes.

The effect of air resistance is neglected.

Coordinates:
x = 10.2 m (horizontal)
y = 0 m (vertical)

Horizontal distance: 10.2 m
Maximum height: 2.55 m

Time: 1.44 s

Initial height: 0 m
Initial speed: 10.0 m/s
Angle of inclination: 45.0 °
Mass: 1.00 kg
Gravitational acceleration: 9.81 m/s²

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Figure 10. Screen Shot of the initial view of Simulation III.

3.3.1 Criteria Used to Select the Simulations

The three simulations were chosen for this research because each exemplified different areas of the design principles, mostly in terms of engagement and coherence, which were outlined in the last chapter. Because they each represented different areas of the design principles, I hoped that it would be possible to identify characteristics of the simulations that affected conceptual change.

Simulation I was chosen to be included in this research because it is a very basic simulation. The layout of Simulation I is straightforward and quite intuitive, and although there are very few functions, ensuring that a user cannot get lost easily, this simulation still contains enough functionality to enable a student who is new to the knowledge domain of projectile motion to investigate the basics of two-dimensional motion. As well, it also allows a user to investigate, and debunk, several misconceptions with respect to the knowledge domain. Simulation I adheres to few of the design principles to encourage engagement that were presented in the last chapter. Of Malone’s (1981) three characteristics of intrinsically motivating learning environments, the simulation contains elements of curiosity, in the very basic sense that it allows user control of variables and allows for cognitive curiosity, but does not contain elements of either challenge or fantasy. While the simulation is tied to learning goals and allows for exploration, motion is not used a tool to encourage interaction, and most users would probably not describe the simulation as fun. Unlike the other simulations, colour is almost absent from the simulation, and is only used as an organizational feature to allow the user to differentiate projectile paths, and so the effect of colour to encourage engagement is not a factor. In terms of controls, the two design principles presented in the last chapter to encourage engagement were the controls should be extensions of the hand, and checkboxes can be detrimental. The controls in Simulation I follow the first principle to a degree, such that sliders are used as well as textboxes, and so the user can manipulate the value of a parameter by dragging a slider if he or she chooses to. However, the checkboxes used in Simulation I, especially the checkbox that allows the user to test for effects due to air resistance, counter the principle presented by Adams et al. (2008b). That research pointed out that once a user checked a checkbox, it was rarely unchecked again, which may mean that the user could forget that the effects of the checkbox are still at work. In the case of this simulation, there was no other indication that air resistance was being accounted for, and so it may have been easy to forget about.

The four factors presented that discourage engagement were not an issue with this simulation. In terms of coherence-related design principles, Simulation I was chosen for this research because of its simplicity. Of the four principles proposed by Kali and Linn (2008) meant to promote coherence, Simulation I seems to primarily follow one, while another is possible: visual complexity is reduced, which follows the principles; multiple-linked representations are possible, but are subject to the ability of the user; and scaffolding and student modelling don't seem to be supported. While Simulation I does allow for the testing of basic misconceptions, it doesn't use exaggerations to enhance coherence, and it doesn't break in a meaningful way.

Simulation II was chosen for this research because it was comparable to Simulation I in terms of its simplicity of the number of variables that could be investigated and the data that was output, but it contrasts Simulation I in that its display is very colourful and its context is game-like. In terms of design principles related to engagement, Simulation II seems to follow the majority of them. It contains elements related to all three characteristics of Malone's (1981) intrinsically motivating learning environments: it has an element of challenge, because it provides a target and provides motivational feedback if the target is hit; it has elements of fantasy, with its multiple projectiles, realistic background, and whimsical statue of David; and it promotes curiosity. Simulation II supports the principles of interactivity: it contains a number of moveable parts and there is plenty of animated motion; its controls are tied to the learning goals; it encourages exploration, although it has some of Kim et al.'s (2007) seductive details; and it has elements of fun. The simulation is built on the platform of Flash, allowing it to have realistic colours and animations, which promote engagement. The controls used in the simulation allow for greater manipulation as extensions of the hand than Simulations I and III, and Simulation II doesn't appear to have any of the four factors that discourage engagement. In terms of design principles related to coherence, Simulation II seems to follow the majority of those as well. It supports three of Kali and Linn's (2008) four principles: it is not visually complex; it supports student modelling by allowing the use of tools in the display area, and it allows for more multiple-linked representations than Simulation I. The simulation also follows two of Adams et al.'s (2008b) three recommendations: it exaggerates the phenomenon, allowing for easier analysis; and it allows for the testing of misconceptions. It is debatable whether the simulation breaks in a meaningful way, such that it allows parameters to be set that aren't realistic, yet it still displays data or it forces values to realistic ones. There are elements of Simulation II that fit Clark and Mayer's (2003) description of extraneous information that may distract from learning. In particular, the animated statue of David, and the ability to choose different projectiles and the corresponding animated landings may distract the user.

Simulation III was chosen for this study because it contrasts with both Simulations I and II. Simulation III contrasts with Simulation I because although it uses a similar sort of output (points are plotted on a set of coordinate axes to illustrate the projectiles' paths), it is capable of a much deeper investigation of projectile motion, allowing the user more variables to input and more options for displaying output. Simulation III contrasts with Simulation II, because although it uses colour extensively and is more detailed than Simulation I, which is similar to Simulation II, its output is geared much more toward being functional rather than game-like. In terms of adhering to design principles related to encouraging engagement, Simulation III follows few. Of the elements of intrinsically motivating environments, the simulation incorporates cognitive curiosity only: there are no elements of challenge or fantasy. Of the principles to encourage interactivity, it only has elements of two, similar to Simulation I: the controls of the simulation are tied to learning goals and they allow for exploration, but motion is not used a tool to encourage interaction, and the simulation would probably not be described as fun. Unlike Simulation I, Simulation III does utilise colour as an organising and differentiating function. However, the simulation is a Java applet, and so the colours are not as subtle, realistic, or three-dimensional as in Simulation II. With respect to controls, Simulation III makes use of only one checkbox, and it should be readily apparent to the user that the effects of the checkbox are at work, but the simulation does not follow the principle that the controls be like extensions of the hand. In terms of design principles related to coherence, Simulation III seems to follow more principles than Simulation I, but less than Simulation II. It supports two of Kali and Linn's (2008) four principles: it supports student modelling and scaffolding, the latter by allowing for multiple analyses the motion being displayed. However, it only allows the analysis of one projectile at a time, and so multiple-linked representations are not easily made. As well, although it is organised into two distinct areas of display and control, there is a great deal of text, and so the simulation doesn't seem to try to reduce visual complexity. Of Adams et al.'s (2008b) three recommendations, Simulation III only allows for the testing of misconceptions.

The three simulations that were chosen for this research represent three different design approaches, as well as three different experiences for students. The goal of these choices was to determine if it is possible to identify whether simulations with engaging characteristics seem to promote conceptual change in students.

3.3.2 Descriptions of the Simulations Used

In the previous section, I presented the criteria that I used to select the simulations for this research. In this section, I will present general descriptions of the simulations which I used to assist me to answer the second research question.

I have chosen to present the descriptions of the simulations using four categories: general layout, use of colour, specific inputs, and specific outputs. General layout refers to the size and scalability of simulation, how its parts are organised, and the relative sizes of its different functional areas. Use of colour refers to how much colour is used in the simulation, and the apparent purposes the colours have. Specific inputs is a listing of the parameters associated to projectile motion that the simulation allows the user to manipulate, as well as the types of interface elements the user can use to manipulate those parameters. Lastly, specific outputs refers to the types of display elements used, the types of data that are displayed for the user as a result of manipulating the simulation, any animations or sounds used to provide information to the user, and any limitations to how much output data can be displayed. The descriptions of the simulations are presented in Table 3 and the simulations can be viewed at the following URLs: Simulation I at http://galileoandeinstein.physics.virginia.edu/more_stuff/Applets/ProjectileMotion/jarapplet.html, Simulation II at http://phet.colorado.edu/en/simulation/projectile-motion, and Simulation III at http://www.walter-fendt.de/ph14e/projectile.htm.

Table 3

Summary of the Descriptions of the Simulations

Description	Simulation		
	I	II	III
General layout	• Occupies about one-quarter of the screen and not resizable • Few controls and simple output • Area is about equally devoted to input and output	• Scalable: user controls size of simulation • More controls, output animated • Mostly devoted to output animations	• Occupies about one-quarter of screen; not resizable • Most controls of the three simulations, mathematical output • mostly devoted to data output for analysis of the motion
Use of colour	• Very little: black and grey text and controls on a white background • Colour used to differentiate projectile paths and output data	• Almost completely coloured • Colour used to simulate reality and to produce contrast between elements	• Almost completely coloured • Colour is only used to produce contrast between elements
Specific inputs	• Allows for the investigation of four variables: mass, angle, velocity, and air resistance • Controls for the continuous variables can be altered by either entering text in a text field or moving a slider bar	• Allows for the investigation of eight variables: mass, angle, velocity, initial height air resistance, diameter, drag coefficient, and altitude above sea level • Variables are manipulated mostly by entering text or dragging cannon	• Allows for the investigation of nine variables: initial height, initial speed, angle of inclination, mass, gravitational acceleration, instantaneous velocity, gravitational force, energy, and displacement • Variables are manipulated solely by entering text in a text field for continuous variables or by clicking radio buttons for dichotomous ones
Specific outputs	• Displays current values of variables • Displays up to five projectile paths • Provides output data for current projectile (range, max height, final velocity, time of flight) • Sound is not used	• Displays current values of variables • Displays an indefinite number of projectile paths • Provides output data for current projectile at one-second intervals during flight and final output data (range, height, and time of flight) • Plays cannon sounds and displays a message if target hit	• Displays current values of variables • Displays one projectile path only • Provides a wide range of output data for the current projectile at any time, including numeric data and vector (graphic) data • Sound is not used

3.4 Data Collected

As I stated in chapter 1, this research is related to further research recommended in a 2008 study by Cronje and Fouche. In that study, two groups of six students were sampled, and the data collection instruments used were a software interaction-tracking program, mental model sketches, and questionnaires. Concept maps were not used because they were deemed to be too resource-intensive for that study. Since the types of data needed for this research were similar to the data needed in that study, I chose similar tools. However, since conceptual change has a greater focus in this research, I selected concept maps as a data-gathering tool to account for this. Three different pieces of data were collected from each participant in this study: concept maps, video records, and responses to interview questions. This section contains information regarding how the information contained in these three pieces of data was coded and analysed.

3.4.1 Concept Maps

The concept maps were constructed and collected according to the guidelines presented earlier in this chapter. The participants constructed pre-treatment concept maps based on what they knew about projectile motion before they started using the simulations. As they used each simulation, they modified their pre-treatment concept maps with coloured ink that corresponded to the simulation they were accessing: red ink for Simulation I, green ink for Simulation II, and purple ink for Simulation III. Once the participants had completed accessing all three simulations, and they had completed making all necessary changes to their concept maps, they completed a post-treatment concept map to capture all of the changes they had made to their working concept maps.

The concept maps were scored at each of these stages, and so each participant had five scores associated with their concept maps: a pre-treatment concept map score, an addition score for Simulation I, an addition score for Simulation II, an addition score for Simulation III, and a final post-treatment concept map score. Since these are just numeric scores, I also analysed the changes represented by the addition scores for Simulations I, II, and III so that the degree of change, and the type of change, in the concept map score could be discriminated.

The concept maps also provided very particular evidence of the exact concept, or concepts, that a participant learned from a particular simulation. Collecting lists of these for the participants corresponding to each simulation was used to examine the effect each simulation might have on the development of particular physics concepts learned by the participants.

3.4.1.1 Description of the Concept Map Scoring Rubric

The two scoring methods described in chapter 2, those proposed by Novak and Gowin (1984) and Besterfield-Sacre et al. (2004) are both reliable ways to score concept maps. However, the analytic method of Novak and Gowin (1984) was more applicable to this research because, although analytic methods are typically more time-consuming, they are more objective and, therefore, more reliable for a single marker to use. In order to apply the holistic scoring system reliably, multiple markers and fairly extensive training and reliability processes would be necessary. Therefore, for the purposes of this research, the pre- and post-treatment student concept maps, as well as the intermediary additions to the pre-treatment concept maps after each simulation was accessed, were scored using the

Novak and Gowin method. This rubric was converted to a tabular form that can be filled out for scoring purposes, and it is presented in Table 4.

Table 4

Tabular Format of the Novak and Gowin Scoring Rubric

Attribute	Description	# of Valid attributes	Value per valid attribute	Student score	Comments
Propositions	The relationship between two concepts is valid and is indicated by the connecting line and linking word.		1		
Hierarchy	The map shows hierarchy and each subordinate concept is more specific or less general than the concept(s) above.		5		
Cross-links	A meaningful and valid connection is made between concepts in two different segments in the hierarchy.		10		
Examples	Specific events or objects that are valid instances of those designated by the concept label.		1		
			Total Score =		

One participant’s concept map proved difficult to score because no linking words were used. This participant was prompted to consider what the concept map was saying, but declined to add the linking words. Although this participant’s concept map contained no valid propositions–linking words are necessary to put concepts together into propositions–it was still possible to score in terms of hierarchies and examples.

3.4.1.2 Concept Map Scoring Sample

This section provides a sample scoring of one participant's concept maps, as well as a short discussion describing the scoring process, to illustrate how the Novak and Gowin (1984) rubric was used in this research. This rubric was used to score the participant's concept map that is presented in Figure 11.

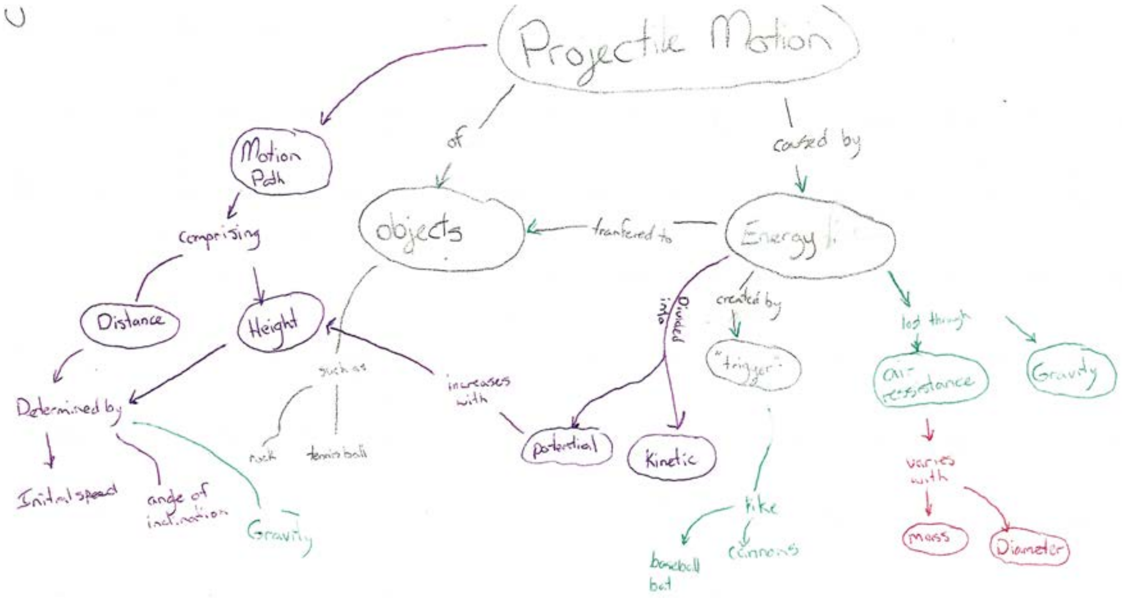

Figure 11. Participant C's working concept map.
Note. Pre-Treatment additions are shown in pencil, and additions after using each simulation are coded by the following colours: Simulation I in red, Simulation II in green, and Simulation III in purple.

The pre-treatment portions of the concept map are those written in black pencil. Table 5 contains the participant's pre-treatment concept map score with comments supplied in the last column.

Table 5

Participant C's Pre-Treatment Concept Map Score

Attribute	# of valid attributes	Value per valid attribute	Student score	Comments
Propositions	**4**	1	**4**	Valid propositions: • Projectile Motion of objects • objects such as rock • objects such as tennis ball • Projectile Motion caused by Energy
Hierarchy	**2**	5	**10**	First = objects and Energy Second = rock, tennis ball, and trigger
Cross-links	**1**	10	**10**	Valid cross-links: • Energy transferred to objects
Examples	**2**	1	**2**	• Rock • Tennis ball
		Total Score =	**26**	

This participant's pre-treatment concept map contained four valid propositions, two valid levels of hierarchy, one valid cross-link between different branches of the concept map, and two valid examples, giving a total pre-treatment score of twenty-six points. Two scoring notes need to be added here. Although the cross-link is a valid proposition, it is only included in the ten-point cross-link category. To include it in both the propositions and the cross-links categories would mean counting it twice in the scoring rubric. However, the two examples that are listed must be added to the concept map by forming valid propositions with another concept in the map. Therefore, in all of the scoring of the concept maps in this research, the concepts that are examples are counted in the examples category, and they are also included in the propositions category if a valid proposition is formed by their addition.

The first simulation that this participant accessed was Simulation II. Table 6 shows the scoring of the additions that the participant made after accessing Simulation II, which are shown in green ink in Figure 11.

Table 6

Participant C's Simulation II Concept Map Score

Attribute	# of valid attributes	Value per valid attribute	Student score	Comments
Propositions	**4**	1	**4**	Valid propositions: • trigger like baseball bat • trigger like cannons • distance determined by gravity • height determined by gravity
Hierarchy	**1**	5	**5**	Added level includes the examples "baseball bat" and "cannons"
Cross-links	**0**	10	**0**	Valid cross-links: • none
Examples	**2**	1	**2**	• Baseball bat • Cannons
		Total Score =	**11**	

After accessing Simulation II, this participant added four valid propositions, one level of hierarchy, and two valid examples. Two propositions, "Energy lost through gravity" and "Energy lost through air resistance", were deemed invalid because energy is conserved in the motion. These additions added eleven points to the participant's concept map score.

The second simulation that this participant accessed was Simulation III. Table 7 shows the scoring of the additions that the participant made after accessing Simulation III, which are shown in purple ink in Figure 11.

Table 7

Participant C's Simulation III Concept Map Score

Attribute	# of valid attributes	Value per valid attribute	Student score	Comments
Propositions	**8**	1	**8**	Valid propositions: • Motion path comprising distance • Motion path comprising height • distance determined by initial speed • distance determined by angle of inclination • height determined by initial speed • height determined by angle of inclination • Energy divided into potential • Energy divided into kinetic Invalid propositions: • Projectile Motion…Motion Path (no linking word)
Hierarchy	**0**	5	**0**	None added
Cross-links	**1**	10	**10**	Valid cross-links: • potential increases with height
Examples	**0**	1	**0**	None added
		Total Score =	**18**	

After accessing this simulation, the participant added a total of nine valid propositions, one of them being a cross-link between two different parts of the concept map. These additions added eighteen points to the participant's concept map score.

The last simulation that this participant accessed was Simulation I. Table 8 shows the scoring of the additions that the participant made after accessing Simulation I, which are shown in red ink in Figure 11.

Table 8

Participant C's Simulation I Concept Map Score

Attribute	# of valid attributes	Value per valid attribute	Student score	Comments
Propositions	**2**	1	**2**	Valid propositions: • air resistance varies with mass • air resistance varies with diameter
Hierarchy	**0**	5	**0**	None added. Although the participant adds these below air resistance, they can be considered as part of the hierarchy already contained in the map.
Cross-links	**0**	10	**0**	None added
Examples	**0**	1	**0**	None added
		Total Score =	**2**	

After accessing Simulation I, the participant added two valid propositions only. These additions added two points to the participant's concept map score.

This participant's post-treatment concept map is shown in Figure 12.

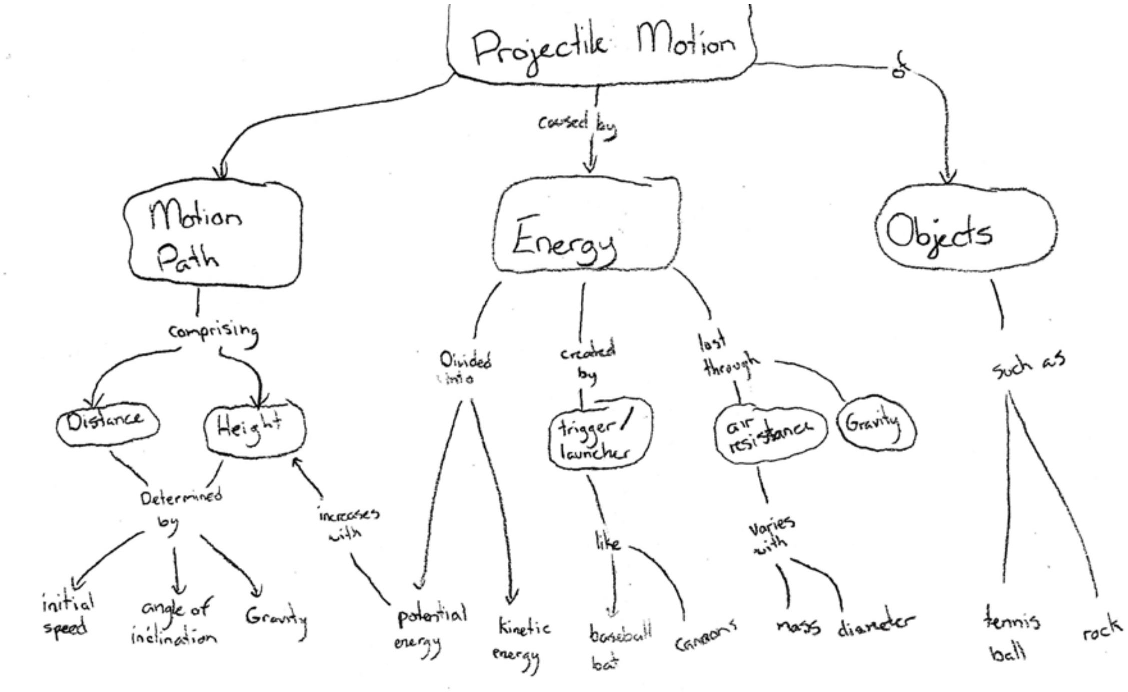

Figure 12. Participant C’s post-treatment concept map.

The post-treatment concept map score for this participant is shown in Table 9.

Table 9

Participant C's Post-Treatment Concept Map Score

Attribute	# of valid attributes	Value per valid attribute	Student score	Comments
Propositions	**18**	1	**18**	Valid propositions: • Projectile Motion of objects • objects such as rock • objects such as tennis ball • Projectile Motion caused by Energy • trigger like baseball bat • trigger like cannons • distance determined by gravity • height determined by gravity • Motion path comprising distance • Motion path comprising height • distance determined by initial speed • distance determined by angle of inclination • height determined by initial speed • height determined by angle of inclination • Energy divided into potential • Energy divided into kinetic • air resistance varies with mass • air resistance varies with diameter
Hierarchy	**3**	5	**15**	Three levels are shown and they increase in specificity
Cross-links	**1**	10	**10**	Valid cross-links: • potential increases with height
Examples	**4**	1	**4**	• Baseball bat • Cannons • Tennis ball • Rock
		Total Score =	**47**	

The scoring procedures shown in the example in this section were applied consistently across all six participants' concept maps.

3.4.2 Video Records

The video records that were collected were simply videotapes of the participants' computer monitors while they accessed the simulations. The goals of videotaping the monitors were to have a record of different actions the participants performed on the simulation, and to determine the amount of time each participant spent accessing each simulation. These data, interactions and access time, form the majority of the data that I will use to demonstrate whether or not the simulations engaged the participants. This engagement data will help to answer the question of whether simulations with engaging characteristics seem to promote conceptual change in students. The methods for gathering this data using the video records are provided in this section.

3.4.2.1 Interactivity Recording

Interactions refer to the actions that the participants performed within the simulations while they were accessing them as observed on the video recordings, and they were each coded as one of the following events: action events, focus events, and other events. The sum of the numbers of these three types of interactions was coded as total events. Each of the videotapes was transcribed into time-based statements of action, and then each of the significant moments (i.e. interactions) were coded as one of the interactions above. Action events were those interactions where the participant used the mouse or the keyboard to make some sort of a change to the simulation that resulted in an effect. Some examples of action events are changing the value of the number in a text box, clicking a radio button, and pressing the fire button in the simulation. Focus events were those interactions where the participant didn't necessarily cause some change or effect in the simulation, but rather drew attention to some part of the simulation. Some examples of focus events are placing the mouse cursor over a particular part of the simulation and pausing for a moment, or selecting text within the simulation but not changing it. Other events were those interactions that didn't quite seem to fit the criteria of either action events or focus events, and often seemed to be erroneous actions. Some examples of other events are the following: right-clicking on part of the simulation, causing a pop-up menu to appear, and then cancelling it by left-clicking; clicking a part of the simulation that wasn't active; and selecting text in a text box, and then changing it to exactly the same value that it was just previously. The total number of each of these types of interactions, as well as their sum, was recorded for each simulation.

3.4.2.2 Access Time

Access time is the total amount of time that each participant spent accessing each simulation. It was collected by noting from the monitor videos the time that each participant launched the simulation, the time that the participant exited the simulation, and then subtracting the two. If the participant left the simulation and came back to it, the new access time was calculated and added to the former access time to determine a total access time.

During each access time, the participants did some or all of the following activities:

- manipulated controls in the simulation,
- entered data,
- observed animations produced by the simulation,
- focused on certain parts of the simulation,
- recorded changes to concept maps, and

- asked the researcher questions.

The access times for each participant were recorded in two different locations. First, the access time for each of Simulation I, Simulation II, and Simulation III was recorded. Second, to determine if order had an effect on access time, each participant's access times were also recorded for the first simulation accessed, the second, and the third.

3.4.3 Interview Responses

Once the participants had finished accessing all three of the simulations, they were individually asked the fourteen questions provided in Appendix A. The first question related to the participants' backgrounds with using simulations. The other thirteen questions can be divided into two question sets, one related to determining the simulations and features of the simulations that the participants liked or disliked, and the other set related to suggested uses of the simulations and their connections to conceptual change.

Seven of the interview questions were designed to determine which simulations, and which features of the simulations, the participants liked or disliked. These were questions 2 through 7 and question 9. Questions 6 and 7 are asked most directly to the point, and they provided the most straightforward evidence as to which simulations students liked the most and, conversely, disliked the most. The participants were able to supplement their responses when they were asked the probing question, "why". This information was used, together with interactivity and access time data, to help determine whether the simulations engaged the participants.

The remaining six questions related to determining what the participants had learned and what possible uses there were for simulations in school. This data was used to supplement discussion of the research in chapter 5.

3.5 Summary

In this chapter, I presented descriptions of the participants of this research and a step-wise listing of the processes those participants experienced. I also presented descriptions of the three simulations used and the types of data I collected from the participants: concept maps, video records, and interview responses. These data sets will be organised in the next chapter with the goal of initiating a discussion about what concepts students might learn when using physics simulations, and whether engaging simulations seem to help promote conceptual change. The data sets will be organised using Adams et al.'s (2008a) two design areas of engagement and coherence, but not the third area of consistency. The two research questions relate to conceptual change and engaging characteristics of simulations, and the data collected support a discussion of these aspects within the areas of engagement and coherence. However, consistency is a design area that was not studied in this research, and so it will therefore, for the most part, be excluded from the analysis and discussion.

CHAPTER 4: ANALYSIS

In Chapter 2, it was suggested that the principles guiding the design of educational simulations could be divided into the areas of engagement, coherence, and consistency, and in chapter 3, I stated that consistency would be excluded from this analysis because it was not part of the research. For the sake of clarity, the data collected in this research will be organized within the remaining two areas, engagement and coherence, in this chapter. The video records of the participants accessing the simulations were coded in terms of interactivity and access time, and the like/dislike interview responses can be grouped such that these data provide indirect evidence of engagement, or whether the simulations engaged the participants or not. The changes that the participants made to their concept maps after accessing each simulation, both qualitative and quantitative, and the other set of interview responses may be related to possible conceptual change and, therefore, coherence.

4.1 Coherence-Related Data

The three simulations selected for this research were designed to allow users to investigate concepts related to projectile motion, and so the learning goals of the simulations should be related to that knowledge domain. In chapter 2, I presented coherence as the relationship of the functionality of the simulation with its learning goals. I believe that the strength of the coherence of a simulation is related to the ability of the simulation to promote conceptual change in the user. If a particular simulation caused a participant to change his or her existing concepts in order to accommodate stimuli from the simulation, then the participant may show this change in one or both of the two data sources of data I have chosen to use to explore coherence. The first is the participants' concept maps, and these were analysed two ways: the concept maps were scored at five points in time, providing quantitative data; and propositions that the participants formed in their concept maps provided qualitative data. Second, six of the interview questions garnered responses related to what the participants had learned and whether they could suggest uses of the simulations in their classroom experience and possible future uses, which provided some data on how well simulations link to learning goals. These pieces of data lay the foundation for a discussion of the coherence of the simulations, or how closely they relate to conceptual change.

4.1.1 Concept Map Scores

A summary of the concept map scores for each participant, including scores for each simulation by name and by order accessed, is shown in Table 10.

Table 10

Summary of Concept Map Scores for Participants

Participant	Pre-treatment	Scores by order accessed			Scores by simulation			Post-treatment	Percent change
		First	Second	Third	I	II	III		
A	5	5	0	0	5	0	0	10	100%
B	25	2	2	0	2	0	2	29	16%
C	26	11	18	2	2	11	18	47	81%
D	7	17	6	33	33	17	6	65	829%
E	32	23	1	10	1	10	23	73	128%
F	16	3	9	5	9	3	5	34	113%
Mean	18.5	10.2	6.0	8.3	8.7	6.8	9.0	43.0	211%
Median	20.5	8	4	3.5	3.5	6.5	5.5	40.5	106%

All of the participants proved to have some understanding of the knowledge domain “Projectile Motion”, as is shown by the scores in the pre-treatment column: all participants were able to score something meaningful. Two participants showed very little improvement with the use of the simulations: participants A and B. However, taking into account that participant A’s concept map was only scoreable in terms of hierarchies and examples because no linking words were used, some improvement was made. Participant B was able to add some valid propositions, but that participant also spent the least time accessing the simulations.

All of the participants showed improvement to their concept maps after accessing the simulations. The smallest score improvement was 16%, while the largest was 829%. The mean and median increases in overall scores from the pre-treatment concept maps to the post-treatment concept maps were 211% and 106% respectively for the participants.

The measures of central tendency, mean and median, used in Table 10 can be easily skewed by the relatively few participants. For example, the mean score changes show that Simulation II produced smaller score changes compared to Simulations I and III, while the median score changes show that Simulation II produced larger score changes compared to Simulations I and III. These are affected by the range of changes between the participants for each simulation, and outlying values affect the results greatly. To analyse which simulation elicited the most (and least) changes to the concept maps of the participants, a summary of the number of participants who experienced the largest and smallest score changes for each simulation was compiled. That summary is shown in Table 11.

Table 11

Summary of Concept Map Score Changes by Simulation

	Simulation order			Simulation		
	First	Second	Third	I	II	III
Largest score change	2.5[a]	2.5[a]	1	3.5[a]	0	2.5[a]
Smallest score change	1	2.5[a]	2.5[a]	2	2.5[a]	1.5[a]

[a]Half numbers of participants indicate ties.

Although the largest score changes and the smallest score changes are spread across the three simulations, five of the participants' scores increased the most after accessing the first two simulations, and five increased the least on the last two. This may suggest that the order in which the participants accessed the simulations does seem to have an overall effect on concept map score changes for this group of participants. However, a larger sample would be necessary to determine if this is the case

Simulations I and III produced the largest score changes for the largest number of participants almost equally, while Simulation II produced the largest score change for the least number of participants: zero. As well, Simulation II produced the smallest score change for the greatest number of participants (three, one was tied with Simulation III). However, the smallest score changes are distributed fairly evenly across the three simulations, and so this result is not as noticeable as the result related to largest score changes.

In summary, all of the participants' concept map scores increased after using the simulations. While Simulations I and III produced the largest score changes for the participants, the simulation that produced the smallest score changes is not conclusive.

As well, it appears that the simulations that were accessed first and second by the participants appear to produce larger changes in concept map scores, but this needs to be confirmed with further research.

4.1.2 Propositions Formed and Conceptual Change

Exactly what concepts did the participants learn from the simulations? A qualitative measure of conceptual change that may have occurred while the participants accessed the simulations is to list the propositions formed by the participants and to classify them as to the level of change to the participants' concept maps. This level of change is related to the amount of cognitive change, and it is related to the rubric shown in Table 4 used to score the concept maps. New propositions and examples likely represent simpler learning, and are scored as one point each. However, adding a level to the hierarchy of the concept map, worth five points, and adding a cross-link between concepts in different parts of the concept map, worth ten points, represent higher mental activities. While specific propositions are summarized in Table 12, it is important to consider the general types of concepts, propositions, and levels of change that each simulation caused. That discussion follows the table.

Table 12

Summary of Valid and Invalid Propositions Formed by Participants Associated with Each Stage of Treatment

Stage of Treatment	Propositions formed	
	Valid	Invalid
Pre-Treatment	• projectile motion is {caused by/made up of} energy • energy transferred to objects • energy such as {elastic/heat} • projectile motion {consists of/contains} force • force like {hitting/throwing} a ball • projectile motion {contains/requires} gravity • gravity which could change weight • projectile motion depends on weight • weight which will determine the {distance/speed} • velocity can become slower because of {wind/air friction} • velocity depends on the object • projectile motion consists of objects • objects such as {rock/tennis ball} • projectile motion requires a launcher • launcher which consists of {angle/objects} • angle which will determine distance	• energy is created by a trigger • force contains energy • energy that is created by force • energy such as electric • projectile motion contains motion • projectile motion of objects • angle which will determine speed
Simulation I	• speed determines distance • projectile depends on {angle/mass} • air resistance varies with {mass/diameter} • objects affected by {velocity/acceleration/friction/force} • acceleration caused by force • maximum height depends on force • initial height finished with a maximum height • weight depends on the object • horizontal distance depends on the initial speed • a time such as 9 seconds	• angle depends on {force/object/initial height/initial speed}
Simulation II	• projectile motion consists of friction • friction which is caused by {size/air} • {height/distance} determined by gravity • launcher controls speed • force depends on the weight of the object • trigger such as {baseball bat/cannons} • objects such as {golf ball/tankshell/bowling ball/Buick} • force such as a canon [sic] • angle such as the angle of the canon [sic]	• energy lost through gravity • energy lost through air resistance • speed depends upon objects • distance depends upon objects • gravity depends on {weight/force/angle} • energy such as explosive
Simulation III	• launcher is used with a variety of initial heights • projectile motion has a force • projectile motion depends on air friction • objects affected by gravity • gravity caused by Earth's pull • motion path comprising {distance/height} • distance determined by {initial speed/angle of inclination} • height determined by {initial speed/angle of inclination} • motion has {initial speed/initial height/coordinates} • velocity is caused by initial force • energy divided into {potential/kinetic} • potential energy increases with height	• angle includes {horizontal distance/ maximum height}

4.1.2.1 Pre-Treatment Propositions

The participants’ pre-treatment concept maps contained valid propositions in five different areas: energy, force, gravity, objects involved, and velocity, which clearly showed what the participants had learned from their Science 10 course. In terms of concepts related to projectile motion, Science 10 focuses on the following areas: types of energy; simple transformations of energy; the relationship of kinetic and gravitational potential energy; the definitions of displacement, velocity, and acceleration, and their arithmetic relationships; a simple definition of work; and a basic understanding of Newton’s first and second laws. Given this background in kinematics, dynamics, and energy, the participants should have been able to speculate on many aspects of projectile motion. They should have been able to attribute energy to projectile motion, and also that this motion consists of a transformation of kinetic and gravitational potential energy: energy is conserved. Participants also should have been able to discern that force must be imparted on a projectile to cause it to be “launched”. Other prior knowledge should have included the fact that the initial velocity of the projectile, related to the force imparted to it, should vary directly with the range of the projectile, and in turn, it should be related to the time of flight of the projectile. Beyond these concepts, the participants would have been using knowledge from outside of their previous, Science 10, course.

The participants used their Science 10 knowledge adequately in their pre-treatment concept maps. For the most part, they formed propositions concerning energy, force, and objects being projected into two levels of hierarchy. Two participants were able to make cross-links, and a total of seven examples were given.

Participant C’s concept map, shown in Figure 13, is a good example that reflects the participants’ uses of Science 10 knowledge.

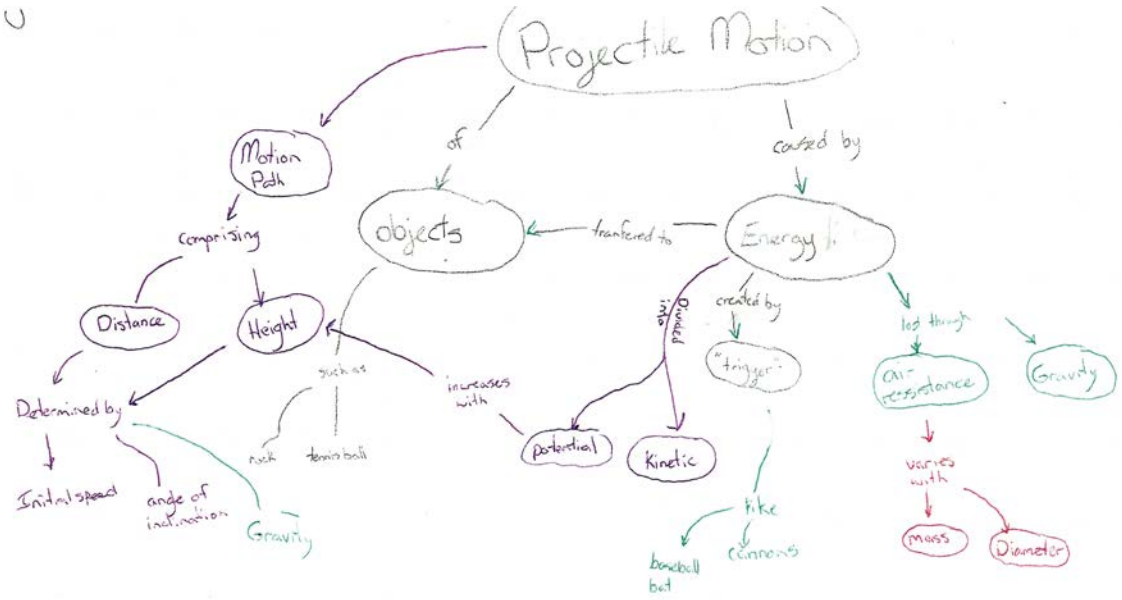

Figure 13. Participant C’s concept map.
Note. Pre-Treatment additions are shown in pencil, and additions after using each simulation are coded by the following colours: Simulation I in red, Simulation II in green, and Simulation III in purple.

The pre-treatment version of the concept map is the work shown in pencil. It shows that the participant organized the concepts of objects and energy into one hierarchy and the more specific concepts of rock, tennis ball, and trigger into a second hierarchy. The Science 10 outcomes related to energy and transformation of energy are likely illustrated by the participant in his or her propositions, “projectile motion caused by energy”, “energy transferred to objects”, and “energy created by trigger”. The last proposition was scored as invalid, but it may reflect a problem with the participant’s inability to use scientific language appropriately rather than a flaw in concept. The proposition “projectile motion of objects” and the exemplar propositions of “ objects such as rock

[and] tennis ball” likely reflect a combination of scientific concepts – mechanical energy transformations must be related to a physical body – and life experience – seeing rocks and tennis balls behaving as launched objects.

4.1.2.2 Simulation I and Conceptual Change

After using Simulation I, participants added a total of fifteen propositions to their concept maps that mainly focused on mass, speed, angle, force, (air) friction, and acceleration. These propositions aligned with the functionality of the simulation. Two of the participants were each able to add one level to the hierarchies of their concept maps, and one participant was able to add three valid cross-links. Participants did not tend to add examples to their concept maps after accessing Simulation I, and this may have been due to the sparse nature of that simulation. Generally speaking, participants added a number of valid propositions, which were not based on examples, and formed very few invalid propositions.

A portion of Participant F’s concept map is provided in Figure 14 because it shows that participants may have begun to re-discover kinematics and dynamics with this simulation.

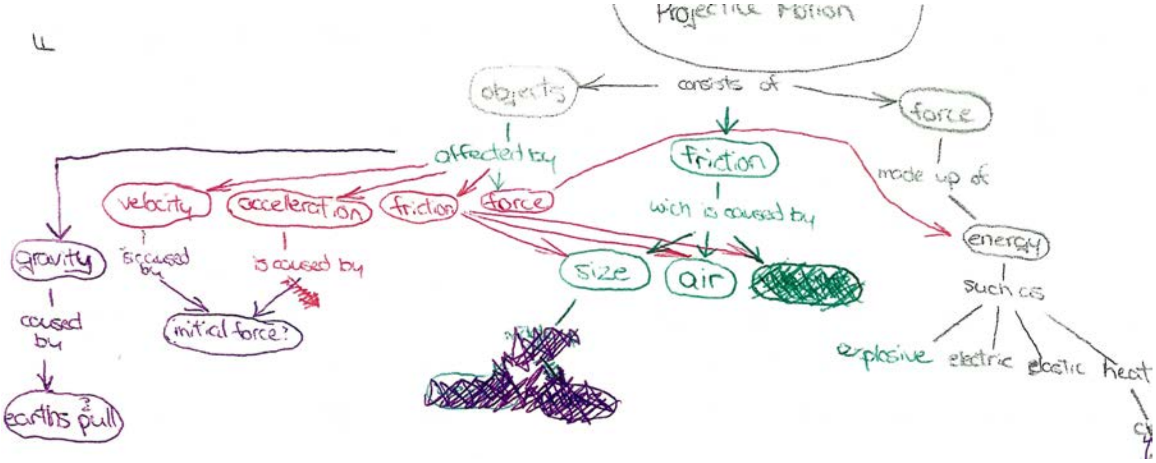

Figure 14. A portion of participant F's concept map.
Note. Pre-Treatment additions are shown in pencil, and additions after using each simulation are coded by the following colours: Simulation I in red, Simulation II in green, and Simulation III in purple.

This participant added the concepts of velocity, acceleration, friction, and force to the concept map. Only the term "velocity" is used in the simulation, so the participant likely related actions in the simulation to prior knowledge. The participant was able to form some valid propositions with the new concepts, and added some linking arrows with no linking words, meaning no propositions were formed in those cases. However, conceptual change may be present. The participant linked force to energy with no linking word, and so the meaning of the link is unclear. It could mean that the participant knows there is a link between the two concepts, and it may not. Similarly, friction is linked with arrows to size, air, and a concept that is crossed out. It appears that the friction that the participant is referring to is air resistance, which is related to diameter, or size, and air density or air current. The participant clarifies this because friction is used as a concept elsewhere in the concept map and linking words are supplied. However, in this earlier instance, the participant had the concept of friction linked to three concepts. After using Simulation I, the participant added another friction concept and another link to the three subordinate concepts. Likely sometime after that, the participant crossed out the third subordinate concept using the colour of ink related to Simulation II. While this likely represents conceptual change, one thing is unclear: if this represents a conceptual change, meaning crossing out the concept means that the participant learned something and realized that the concept was no longer valid, then which simulation effected this change? This is a limitation of this research and the scoring rubric used, and it is provided in more detail, along with other limitations, in chapter 5.

4.1.2.3 Simulation II and Conceptual Change

After using Simulation II, participants added fifteen valid and eight different invalid propositions to their concept maps that incorporated the concepts of angle, mass, air resistance, gravity, and “triggers”. Participants also added a great number of examples to their concept maps after using this simulation: seven in total, as opposed to totals of one example for each of the other simulations. These examples accounted for a number of the propositions added to the concept maps, and were entirely composed of types of projectiles that could be found in the part of the simulation that allowed the user to choose the type of projectile to fire. Although using examples to build propositions is valid within the rubric, concept map scores for this simulation may have been inflated because of the total forty-one points that the six participants added to their concept maps after using this simulation, fourteen were due to simple propositions that were formed using examples. Beyond the propositions, three of the participants were able to add at least one new hierarchical level to their concept map (one participant added two), but not one participant was able to form valid cross links. The addition of one level to the hierarchy was also affected by the number of example-concepts generated by this simulation, because the lowest subordinate level added consisted of examples.

Participant E’s concept map is shown in Figure 15 to illustrate this.

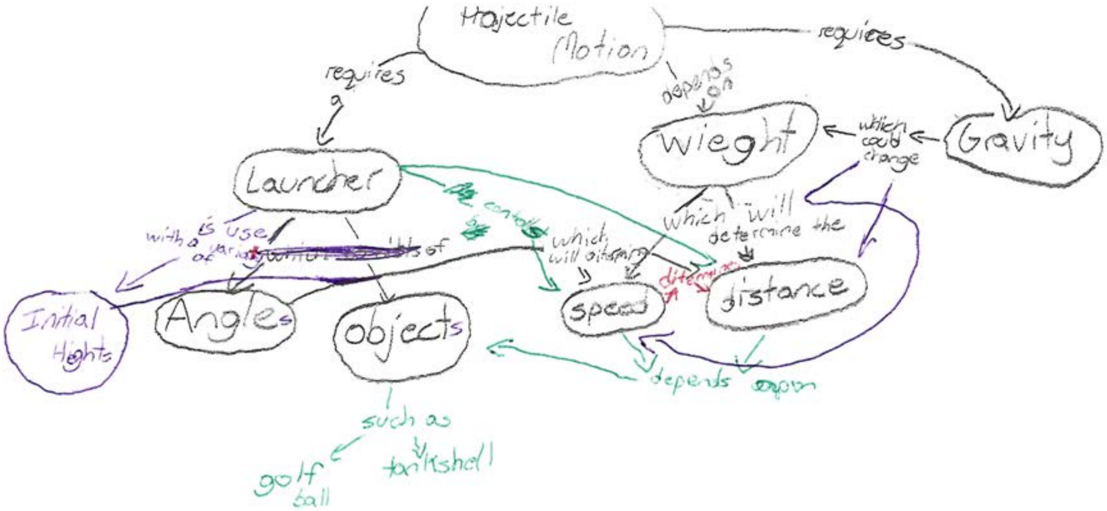

Figure 15. Participant E’s concept map.
Note. Pre-Treatment additions are shown in pencil, and additions after using each simulation are coded by the following colours: Simulation I in red, Simulation II in green, and Simulation III in purple.

The green ink shows that the participant formed the valid propositions that the launcher controls the speed and distance, but also formed the invalid propositions that speed and distance depend upon objects. Again, the invalidity of these propositions may be due to the inability of the participant to use language appropriately to convey meaning. The important part of the concept map to note is that this participant’s score, like others’ scores, is greatly affected by addition of examples. This participant added the propositions “objects such as golf ball” and “objects such as tankshell” into a new hierarchy, an addition of seven points, that reflect additions of examples to the participant's knowledge domain of projectile motion, which may not be viewed as deeper scientific conceptual change.

4.1.2.4 Simulation III and Conceptual Change

After using Simulation III, the participants formed twenty-six valid and two invalid propositions based on the concepts of distance, height, initial height, position, force, air friction, gravity, and energy. As with the other simulations, these concepts aligned well with the functionality of the simulation. However, the majority of the participants did not access the richer features of this simulation, and so the changes to their concept-map scores could possibly have been higher. Even so, the sum of the number of propositions formed by participants was highest for Simulation III. The concept map scores of the participants could have been higher for this simulation if they would have been able to form propositions in the two categories that represent higher levels of cognition: hierarchies and cross-links. Although they were attempted, no valid hierarchical levels were added after accessing this simulation, and only two participants were able to form a total of three valid cross-links.

Participant D's concept map illustrates these changes well, and is shown in Figure 16.

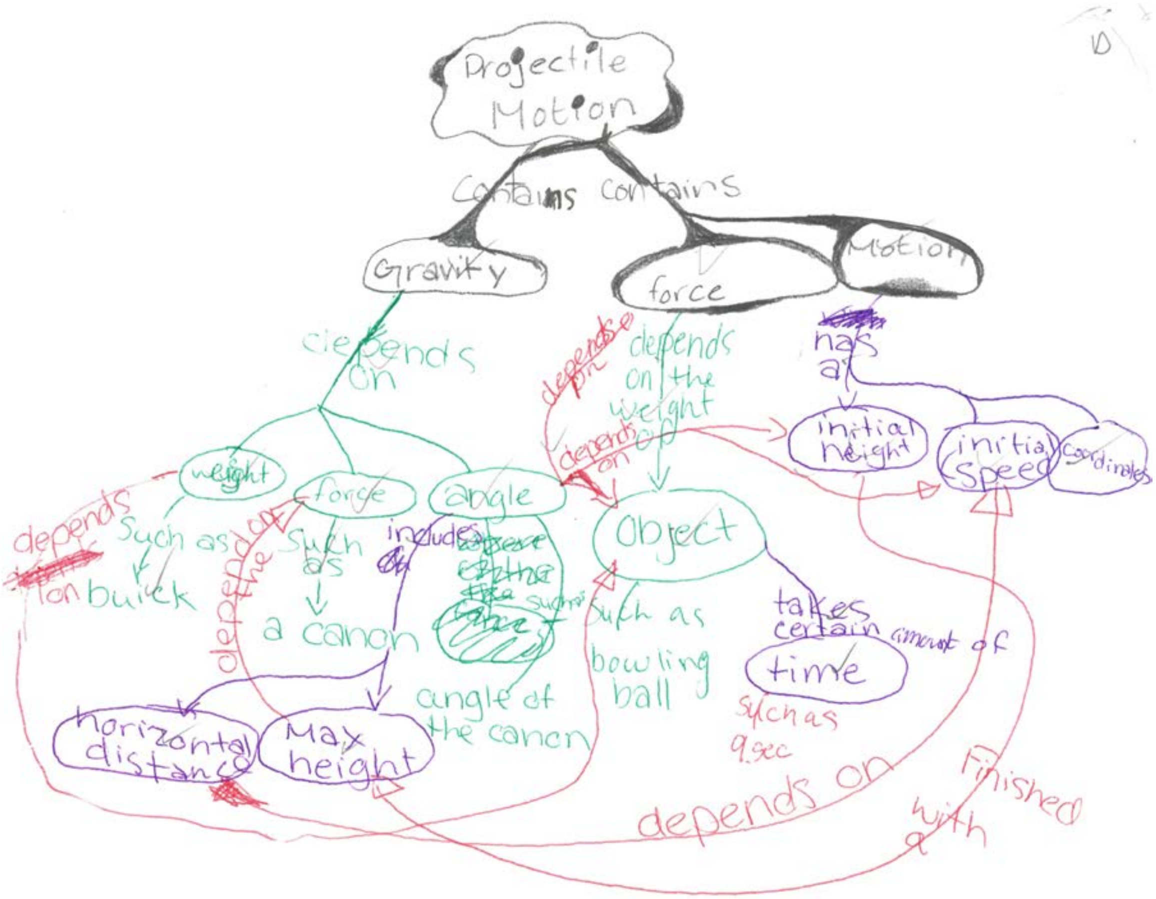

Figure 16. Participant D's concept map.
Note. Pre-Treatment additions are shown in pencil, and additions after using each simulation are coded by the following colours: Simulation I in red, Simulation II in green, and Simulation III in purple.

The parts of the concept map shown in purple ink represent the additions made after using Simulation III. Some valid propositions are made regarding the motion and its relationship to initial height, speed, and coordinates, as well as time of flight. Invalid propositions include those relating angle to horizontal distance and maximum height. As was stated earlier, one of these invalid propositions may be so because of an inability to use language appropriately: in this case, cause and effect. Angle is related to maximum height of a projectile, but it doesn't "include" it. More appropriately, angle helps determine maximum height. Most importantly, this concept map illustrates the fact that participants were unable to add hierarchical levels to their concept maps after using Simulation III. Rather, the propositions formed were incorporated into existing levels.

Based on this small sample, Simulation I seemed to allow the participants to add the most higher scoring types of additions to their concept maps. This could be summed up by saying that the participants added the fewest propositions, but the propositions that were added represented all aspects of functionality of the simulation and were constructed such that they represented higher levels of learning. Simulation III seemed to allow participants to add the most valid propositions across the broadest range of concepts without incorporating examples, but these propositions were organized into existing hierarchies and with no new cross-links. In summary, the participants constructed the most basic propositions using Simulation III, but were unable to construct higher meaning. Simulation II seemed to allow the participants to generate the most examples, which were in the form of valid propositions, and which often allowed for a new level to be added to the hierarchical structures of the concept maps. However, examples are fairly easy to incorporate, and so one might argue that since the participants spent the most time accessing this simulation, they may have been able to form higher meanings if the simulation were more efficient.

4.1.3 Interview Responses Related to Coherence

Beyond using the changes to the participants’ concept maps to determine whether conceptual change took place or not, interview questions were asked of participants to determine whether they had learned anything from the simulations are not. The first question in the interview simply asked if they'd used the simulations before and for what purpose. Four of the participants had never used the simulations before, and the two that had used them had limited exposure to games in one case, and some simple science demonstrations in the other case.

The remaining five questions could be divided into two areas: any conceptual change the simulations may have promoted, and possible uses of simulations in school settings. In responding to the questions related to whether the simulations promoted any conceptual change in them, the participants overwhelmingly responded that the simulations caused them to think of questions to ask their teacher. Most of the questions that the participants stated they would ask were of a clarifying nature: “How do you figure out your initial speed?", and "a little more on kinetic and potential energy". When asked what they had learned, most of the responses focused on specifics, such as different variables and their effect on projectiles, and discovering that, "there is a lot of different things that could change it that I hadn't thought of”. These participants may be placed at the eliciting pre-conceptions or creating cognitive conflict stages of Zhou’s (2010) argumentation model of teaching, shown in Figure 4 in chapter 2. This suggests that there are parts of the simulations that are missing or that do not fit with their existing knowledge, and they are making those inconsistencies present and searching to rectify them. In the Posner et al. (1982) conceptual change model, these participants are working to either assimilate the new stimuli or accommodate new conceptions. Regarding the uses of simulations in school, the participants felt that simulations could be of benefit if they were used more regularly, because, "I like to see it rather than just read about it", and "it would be more interesting and fun I think". The specific uses that they gave were quite varied: mathematics, in order to help learn trigonometry and angle classifications; chemistry in order to do titrations in a safe environment; science, especially when dealing with strong solutions; science for learning food chains, webs, and ecosystems; and art class, in order to experience styles without making a mess or wasting materials. However, the participants also felt that simulations could be used too often, such that "we could rely on them too much instead of doing the actual lab, and you don't really learn". When asked whether simulations could replace teachers in some situations, the participants overwhelmingly replied that teachers are necessary because, “Teachers could explain things you don't understand. Simulations can help, but teachers need to do the instructions first."

In this section, the data collected to support a discussion on coherence was presented. This data consisted of qualitative and quantitative evidence gathered from the participants’ concept maps, and the interview responses related to what the participants learned from the simulations and what the participants felt would be appropriate uses for the simulations in school. Coherence is one of the principles that can be used to guide the development of educational simulations. In the next section, I will present the data related to the other principle relevant to this research: engagement.

4.2 Engagement-Related Data

The three simulations selected for this research were chosen because they met the criteria for engagement that were identified in chapter 2 to varying degrees (e.g. motion, fun, colour, intuitive controls, and feedback). I assumed that if a particular simulation engaged a participant, then he or she may spend more time using the simulation and interacting with it more often. As well, if a participant liked a simulation, then I assumed the simulation engaged him or her. The data I have chosen to relate to engagement comes from three sources identified in chapter 3: interaction coding from the video records, access time calculated from the video records, and the seven interview responses related to like/dislike. These three pieces of data lay the foundation for a discussion of the participants' engagement with the simulations.

4.2.1 Interactions

As was stated in chapter 3, the participants' actions they performed while accessing the three simulations were coded as action events, focus events, and other events. The summary of the numbers of each of these interactions for each participant for Simulations I, II, and III, as well as the numbers of these interactions according to the order in which the participants accessed the simulations, is shown in Tables 13 and 14.

Table 13

Summary of Participants' Interactions with Simulations by Number of Simulation

Participant	Event type	Simulation		
		I	II	III
A	Action	28	41	51
	Focus	7	1	2
	Other	0	0	0
	Total	35	42	53
B	Action	11	124	46
	Focus	2	0	11
	Other	1	0	12
	Total	14	124	69
C	Action	5	180	46
	Focus	3	0	8
	Other	0	1	1
	Total	8	181	55
D	Action	1	41	4
	Focus	0	4	3
	Other	0	3	0
	Total	1	48	7
E	Action	39	95	37
	Focus	2	6	3
	Other	2	2	5
	Total	43	103	45
Averages	Action	**17**	**96**	**37**
	Focus	**3**	**2**	**5**
	Other	**1**	**1**	**4**
	Total	**20**	**100**	**46**

Note. The camera for participant F failed intermittently, so interaction data is not available.

Table 14

Summary of Participants' Interactions with Simulations by Order of Use

Participant	Event type	Simulation order		
		First	Second	Third
A	Action	28	41	51
	Focus	7	1	2
	Other	0	0	0
	Total	35	42	53
B	Action	11	46	124
	Focus	2	11	0
	Other	1	12	0
	Total	14	69	124
C	Action	180	46	5
	Focus	0	8	3
	Other	1	1	0
	Total	181	55	8
D	Action	41	4	1
	Focus	4	3	0
	Other	3	0	0
	Total	48	7	1
E	Action	37	39	95
	Focus	3	2	6
	Other	5	2	2
	Total	45	43	103
Averages	Action	**59**	**35**	**55**
	Focus	**3**	**5**	**2**
	Other	**2**	**3**	**0**
	Total	**65**	**43**	**58**

Note. The camera for participant F failed intermittently, so interaction data is not available.

The number of interactions performed on the simulations varied greatly by participant. The fewest total number of interactions with a simulation was one (participant D while accessing Simulation I, the third simulation that participant accessed), and the highest total number of interactions with a simulation was 181 (participant C while accessing Simulation II, the first simulation that participant accessed).

Simulation II elicited many more total interactions than both Simulations I and III. Simulation III, in turn, elicited more total interactions from participants than Simulation I. Interestingly, Simulation III elicited the most other events of the three simulations. This may be due to the fact that participants may have found navigating Simulation III more difficult; the other events recorded for this simulation tended to be clicking on a button that was inactive (the simulation needed to be reset to make the button active).

It appears that there is some question as to whether order had an effect on the number of interactions participants had with a simulation. The first and third simulations accessed seem to have higher numbers of interactions than the second simulation accessed. However, this can be explained somewhat by the fact that, due to a problem accessing some of the simulations, the participants didn’t follow the assigned orders exactly: Simulation I was accessed first by two participants, second by two participants, and third by two participants (the expected assignments); Simulation II was accessed first by three participants, second by only one participant, and third by two participants; Simulation III was accessed first by one participant, second by three participants, and third by two participants. Since Simulation II had many more interactions from the participants than the other two simulations, and it was accessed more in the first and third serial orders, slightly higher numbers can be expected for the first and third simulations accessed. With this in mind, it doesn’t appear that order affected the number of interactions elicited from participants by a simulation.

A summary of the number of participants who had the most and least interactions with particular simulations is shown in Table 15.

Table 15

Number of Participants Interacting the Most/Least with Particular Simulations

	Event type	Simulation order			Simulation		
		First	Second	Third	I	II	III
Most interactions	Action	2	0	3	0	4	1
	Focus	2	2	1	1	2	2
	Other[b]	2.5[a]	1.5[a]	0	0	1.5[a]	2.5[a]
	Total	**2**	**0**	**3**	**0**	**4**	**1**
Least interactions	Action	3	0	2	4	0	1
	Focus	1	2	2	2	3	0
	Other[b]	0	1	3	2	1.5[a]	0.5[a]
	Total	**2**	**1**	**2**	**5**	**0**	**0**

Note. The camera for participant F failed intermittently, so interaction data is not available.

[a] Half numbers of participants indicate ties. [b] Partcipant A did not show any other events for any simulation. This row has a sum of four.

This summary shows that Simulation II overwhelmingly elicited the most interactions from the most participants, while Simulation I overwhelmingly elicited the least interactions from the most participants. This summary also amplifies the effect of having Simulation II accessed most often as the first or third simulation.

In summary, the data presented above show that Simulation II garnered the most interaction with participants, Simulation I the least, and the order in which the participants accessed the simulations doesn't appear to affect this result.

4.2.2 Access Time

The time that a participant spent accessing a particular simulation can be considered as one of the pieces of evidence of engagement. A summary of the participants' access times for Simulations I, II, and III, as well as the access times according to the order in which the simulations were accessed, is shown in Table 16.

Table 16

Summary of Participants' Times Spent Accessing the Simulations

Participant	Simulation order			Simulation		
	First	Second	Third	I	II	III
A	09:21	13:01	14:43	09:21	13:01	14:43
B	01:44	05:06	05:48	01:44	05:48	05:06
C	18:11	14:26	04:02	04:02	18:11	14:26
D	13:10	04:33	06:31	06:31	13:10	04:33
E	07:42	07:51	09:55	07:51	09:55	07:42
Averages	10:02	08:59	08:12	05:54	12:01	09:18

Note. The camera for participant F failed intermittently, so interaction data is not available.

All of the participants except participant A spent the most time accessing Simulation II. This is shown collectively by the average access time for the five participants in the study: it is higher for Simulation II than Simulation III, and it is more than double the average access time for Simulation I.

Three of the five participants clearly spent the least time accessing Simulation I. One of the participants, participant D, had the lowest access time for Simulation III. Participant E clearly spent the most time accessing Simulation II, but that participant's access times for Simulations I and III differ by only nine seconds. These access times are so close that, for the purposes of this research, they will be considered equal. Therefore, four of the five participants, spent the least time accessing Simulation I (although one of the participants' times was equal for Simulation III), while the fifth participant spent the least time accessing simulation III. Three of the participants had the highest access times for the third simulation they launched, while two of the participants had the highest access times for the first simulation they launched.

As mentioned earlier, the access times for participant E for two of the simulations differ by only nine seconds, and they are being considered equal for this research. Therefore, participant E spent the least time accessing the first and second simulations launched. Of the remaining four participants, two had the lowest access times for the first simulation, one for the second simulation, and one for the third simulation.

In terms of average access times for the order of simulation accessed, the first simulation had the highest average, the second simulation the next highest average, and the third simulation the lowest. However, the averages did not differ greatly, and so it does not appear that the order in which the participants accessed the simulations had an effect on access time.

In summary, and in general, the participants spent the most time accessing Simulation II, the least time accessing Simulation I, and the order in which the participants accessed the simulations doesn't appear to have an effect on access time.

4.2.3 Like/Dislike Interview Responses

The goals of asking the seven questions related to the participants' like and dislike of the simulations and their features were two-fold: to compare to the other measures of engagement of interactivity and access time; and to identify whether these participants could confirm any of the principles of simulation design presented in chapter 2. The participants' responses to these questions showed common themes that are summarised in this section.

4.2.3.1 Most Liked and Disliked Simulations

The interview responses clearly showed that the majority of participants, five, liked Simulation II the most, while the participants were evenly split whether they disliked Simulation I or III the most. These results were checked against the order in which the participants accessed the simulations, and an effect appears. In terms of which simulation the participants liked the most, order did not seem to have an effect; the responses were evenly distributed across the orders of access. However, when one looks at the simulation that the participants disliked the most, order may have an effect: none of the participants disliked the first simulation that they accessed the most, three of the participants disliked the second simulation the most, and three of the participants disliked the third simulation the most. This information is summarized in Table 17.

Table 17

Summary of the Simulations that Participants Liked/Disliked the Most

	Simulation order			Simulation		
	First	Second	Third	I	II	III
Liked most	2.5[a]	2	1.5[a]	.5[a]	4.5[a]	1
Disliked most	0	3	3	4	0	2

[a]Half numbers of participants indicate ties.

One of the common themes regarding like and dislike of the simulations centred on the context of the simulation. The participants liked Simulation II because it was, “more or less realistic…to a certain point”, and this made the concepts, “easier to visualize”. Beyond realism, the participants’ responses show preferences for the characteristics of fun and game-like feel: "giving the amusing situation with more information would be great", and Simulation II, "was like a game, so it was okay", while Simulation I was described as, “boring”.

A common theme arose regarding the interface and its elements. Participants mentioned the topic of colour and its use in the simulation interfaces in their responses to several questions. The participants’ responses showed agreement that use of colour was a source of positive responses about a simulation. Simulation I was described as, "plain... no colour, hard to keep interested", and a way to improve it would be to, " put more colour, more appealing colour... it would be more appealing and easier to stay focused.". Besides liking colour, the participants’ responses indicated a preference for interfaces that are intuitive over interfaces that are confusing. The participants described Simulation III as, "confusing... wasn't as easy to manipulate or to change the numbers", while they described Simulation II as easy to use.

Another common theme that was contained in the interview responses pertained to the controls. Participants showed a preference for controls that were manipulated using the mouse, but disliked controls that were simply textboxes that required the participants to type. One participant remarked, "you had to type in on the others; you just selected on this one”. As well, participants disliked the use of too much unfamiliar terminology, because it caused confusion and the participants weren’t sure how to proceed.

The last common theme contained various aspects of the learning environment. Participants’ responses reflected a preference for the ability of simulations to allow for self-pacing, but they disliked not having someone to guide them. The participants liked that the simulations allowed for choice, which was reflected in the response, "I could change the numbers and make it my own". As well, the participants recognised the strategy of scaffolding, and liked that the simulations allowed for multiple ways to navigate the simulation, meaning the participant, “could try it in a different way".

The key ideas contained in all of these like and dislike related responses are summarised in Table 18.

Table 18

Summary of Participants' Likes and Dislikes

Likes	Dislikes
• Simulation II	• Simulation I
• Selecting actions	• Typing actions
• Colourful interface	• "Boring" interface
• Realism	• Confusing interface
• Game-like feel	• Too much terminology
• Intuitive interface	• No guidance
• Self-pacing	
• Choice	
• Scaffolding – ability to do tasks in multiple ways	
• Amusing or fun context	

Overall, the participants of this research liked Simulation II the most, disliked Simulation I the most, and while order didn't appear to affect which simulation the participants liked the most, it may have an effect on which simulation they disliked the most.

In this section, the data collected to support a discussion on engagement was presented. This data consisted of the amount of interactivity the participants had with the simulations in terms of numbers of actions performed and time spent interacting, and the interview responses related to what simulations and simulation features the participants liked and disliked.

In this chapter, the data collected from this research was organised and presented in a way to facilitate discussion, and that discussion is the final chapter of this paper.

CHAPTER 5: DISCUSSION AND CONCLUSION

5.1 Introduction

This chapter is organised around the two research questions that guided this study:

1. What conceptual changes do we see when students use physics simulations?
2. Do simulations with engaging characteristics seem to promote conceptual change in students?

This chapter will address these questions based on the data presented in the previous chapter. It will also present the possible implications of this research for 21st century physics classrooms student-centred teaching strategies. The chapter concludes with suggestions for further research.

5.1.1 What Conceptual Changes Do We See When Students Use Physics Simulations?

In this research, evidence for conceptual change came from the concept maps and interview questions. The participants' concept maps provided both quantitative evidence (increases in their scores), and qualitative evidence (increases in the number of valid propositions formed and in the types of changes the participants made to them) of possible conceptual change. Through their concept maps, participants were able to communicate their understandings of the projectile motion knowledge domain in terms of their Science 10 and pre-existing science knowledge. They were also able to expand on their knowledge after using the simulations. The participants formed propositions about projectile motion mainly pertaining to the concepts of energy, gravity, and simple air resistance effects. They also incorporated new concepts related to initial speed and initial angle, and how these affect range and maximum height. They were able to enhance their understanding of air resistance somewhat, although not to the extent that the simulations might have allowed them to. The participants were also able to incorporate examples into their understanding of projectile motion by adding them to their concept maps in valid ways. These conceptual changes occurred immediately after using the simulations, hence it is reasonable to assume the simulations affected the students' conceptual understanding of projectile motion.

Much of the conceptual change demonstrated by the participants was somewhat superficial. This was reflected not only in the scores and descriptions of the concept maps, but in the interview responses as well. The concept map scores reflected that most of the participants underwent more simple conceptual changes, in the form of additional concepts, propositions, and examples, and fewer participants experienced more complex conceptual changes, in the form of additional levels of hierarchy and cross-links. Although there were increases in concept map scores for all participants, and this is likely evidence that conceptual change occurred, the vast majority of it was less challenging cognitively: most of the changes to the concept maps represented propositions and examples. All participants were able to at least partially organise their concept maps with hierarchies, but only three of the participants were able to form cross-links. In the interview questions, when asked what they had learned, and whether the simulations caused any questions to come to mind, the participants' responses did not reflect deep learning. All of the responses presented in chapter 4 show that the participants wanted to ask questions about terms in the simulations, or to get more information regarding them. These results may have been due to the haphazard ways participants navigated the simulations, and I would hypothesize that if the participants had been given some specific tasks to investigate, higher order conceptual change might have occurred.

Many of the propositions formed fit well with the participants' previous science knowledge. It would appear that they were able to deal with the new phenomena using the process of assimilation in Posner's model of conceptual change rather than accommodation. For accommodation to be necessary, the four conditions in Posner et al.'s (1982) model would need to be met: the learner must be dissatisfied with existing conceptions; the new conception must be intelligible to the learner; a new conception must appear to be initially plausible, such that the learner sees immediately that there are possibilities for it to solve problems that the predecessor concepts could not; and a learner should be able to see the potential of the new concept to provide new areas to delve into. The participants' concept maps or interview questions likely would have showed dissatisfaction with existing conceptions, such as scratching out previous notations on the concept maps or interview responses stating that phenomena in the simulations didn't make sense. It does not appear that any of the new information in the simulations necessitated a radical change to the conceptual frameworks of the participants, and so accommodation likely didn't occur.

It should also be noted that the participants formed propositions that were invalid as well, and while these represent conceptual change, it is not desired change. Participants formed propositions related to gravity, mass, and velocity that were especially worrying. With respect to gravity, participants stated that energy is lost to gravity during a projectile's flight, and gravity depends on weight, force, and initial angle. The former goes against the energy conservation and energy transformation lessons the students would have received in Science 10, while the latter indicates either a reverse relationship or a relationship that doesn't exist. These findings, as well as all of the findings presented in this section, will help guide the discussion in the next section.

5.1.2 Do Simulations With Engaging Characteristics Seem To Promote Conceptual Change In Students?

Which simulation seemed to engage the students the most, and did that simulation appear to promote the most conceptual change? In order to determine this, data from both of the areas of engagement and coherence are necessary.

Consider the engagement of participants with the simulations first. In this study, participants were given the opportunity to access physics simulations in an unguided way: there was no script, and no guiding questions were given. Therefore, how well the participants were engaged by the simulations, and how well the simulations motivated them to interact, may have been crucial.

The work of Adams et al. (2008a; 2008b), which was used as the foundation for much of the design of Simulation II, seems to place a great deal of emphasis on engagement, with the intention of developing deeper conceptual understanding. The data shows some interesting trends and contradictions. In chapter 4, I presented the data that showed participants spent the most time accessing, recorded the most interactions with, and had the most like-related comments about Simulation II. They spent the least time accessing and interacting with Simulation I, and they provided the most dislike-related interview responses for that simulation. It can be said that participants were most engaged by Simulation II and least engaged by Simulation I, and these results seem to be dependent on the characteristics of the simulations themselves. Interactions are related to access time such that it is likely common for the number of interactions and the length of access time to vary directly with one another, and it is also likely that students would report liking the simulation that they spent the most time interacting with and accessing. The only caveat to this is that the rate at which the interactions are done, and the limiting number of interactions, may be driven by interest.

Contrary to the engagement result, the concept map scores show the opposite: participants had the lowest score changes after accessing Simulation II and the highest score changes after accessing Simulations I and III. In order to examine this contradiction, three observations should be pointed out. First, the use of colour and animations in Simulation II provided a setting that participants may have been interested in: a sensory curiosity. This is supported by positive interview responses regarding the use of colour and realism, and negative comments about Simulation I calling it “boring”. This reflects that participants felt that Simulation II was likely more engaging than the other simulations. Coupled with this are comments about Simulation III being “confusing”, along with the higher number of other events recorded. This may mean that participants found Simulation II the easiest of the three simulations to engage with due to its realistic colour and graphics, as opposed to the coordinate planes and single-gradient colouring of the other simulations. However, since these characteristics may have only stimulated sensory curiosity, rather than cognitive curiosity, the participants may have derived more enjoyment than conceptual change from using Simulation II. Second, Simulation II provided feedback that may have also promoted emotional interest (Kim, et al., 2007), again sensory curiosity, and that may have evoked sensory arousal in the participants: the cannon flashed with each shot and the “SCORE!” message displayed each time the target circles were hit. Video evidence showed participants pressing the “Fire” button of this simulation without changing the parameters for the projectile, sometimes even before the projectile had completed its path, possibly to simply view the cannon flash over and over. Simulations I and III did not appear to provide elements for emotional interest. As with the first point made above, the participants may have experienced more enjoyment than conceptual change from using Simulation II. Third, and somewhat related to the point made above, there was an element of choice available to participants in Simulation II, giving it an element of fun. Participants spent a great deal of access time and action events using the control in the simulation that allowed them to choose the type of projectile to be fired. This certainly increased the engagement attributed to Simulation II, but the purpose of the control introduces questions related to the effect on learning. While Simulations I and III simply plot points on two-dimensional Cartesian planes, Simulation II allows the user to fire animated cannon balls, golf balls, baseballs, pumpkins, pianos, cars, tank shells, and even human beings. Most of these animated projectiles have animated landings as well: the pumpkin breaks into bits, the piano and car smash apart, the human being looks dejected, and so on. Participants spent a great deal of access time and recorded a large number of action events simply choosing different projectiles and pressing the “Fire” button on the same initial velocity and angle again and again. This led to inflated measures of interactivity. It would appear that this control could be classified as a distractive detail (Clark & Mayer, 2003), something which tends to draw the user away from important information and which may have a negative effect on learning (Kim, et al., 2007). This was one of the problems that the team that designed Simulation II, advised by the work of Adams et al. (2008a; 2008b) had with other simulations: unintended consequences of making certain animations too enjoyable, allowing the user to spend time playing with the animation rather than investigating the science content.

Descriptions of the qualitative changes to the participants' concept maps may illustrate a few points about the contradiction of engagement results being contrary to concept map scores. First, the changes to participants' concept map scores after using Simulation II were affected by the number of examples extracted directly from the simulation by the participants, and these conceptual changes inflated concept map scores. Second, participants added many more invalid propositions after using Simulation II than after using either Simulation I or III. Many of these focussed on gravity or energy loss. It may be that Simulation II, with its ability to illustrate a variety of projectiles with masses that change automatically when a new projectile is chosen, together with its inability to output related, clarifying information, caused the participants to form propositions that were invalid: this may have been an example of Clark and Mayer's (2003) disruptive details. Third, Simulation I showed the smallest number of additions to the concept maps, but these additions were due to the higher cognitive activities of hierarchy-building and cross-linking, even though participants were engaged the least by Simulation I. All three of these points provide evidence that Simulation I adhered to the coherence principle more closely than Simulation II.

With all of this in mind, we come back to the question of whether simulations with engaging characteristics seem to promote conceptual change. To this point, I have treated coherence as a separate entity from engagement. While engagement seems to be related to those characteristics which stimulate interest, coherence seems to be a subset of engagement, and so I believe the two are closely related. The measures that I used for coherence likely show whether a simulation promoted conceptual change or not. For a student to experience conceptual change while using a simulation, he or she must be engaged by it. However, this engagement must be more than just a sensory curiosity as it is described above. I believe that a simulation must stimulate cognitive curiosity for conceptual change to occur, and this is related to coherence. This cognitive curiosity is addressed in both Posner's model of conceptual change, especially in the conditions for accommodation, and in Zhou's model for teaching science, especially in the stages where the teacher provokes the students with anomalous phenomena and debate. In short, simulations that seem to engage students may not necessarily satisfy conditions of coherence, but simulations that seem to promote conceptual change (i.e. they satisfy conditions of coherence) seem to, at least to some degree, engage students.

Fun, choice, and realistic animations are all part of Simulation II, but not Simulations I and III which showed the greatest conceptual changes. Colour was identified as important by both the literature and by the participants, yet Simulation I incorporates very little colour. Engagement was highest for Simulation II, but much lower for Simulations I and III. It would appear that Simulation II emphasizes engaging students based on emotion interest, or sensory curiosity, while Simulation I and III emphasize engaging students based on cognitive curiosity, and this appears to be more effective at promoting conceptual change.

Little can be concluded about the individual characteristics of simulations that promote conceptual change in students. However, one can identify characteristics that impeded conceptual change in this research. Perhaps the most pervasive factor in all of the results was the influence of the control in Simulation II that allowed users to choose the projectile being fired. This was likely a distractive detail for the participants. It contributed greatly to engagement by inflating access time, number of interactions, and positive comments. It also contributed to a number of the gains in concept map scores related to using the simulation, even though those gains did not necessarily reflect deeper learning. If the designers had chosen to limit the choices in this control, or limited the projectile types to one, such as a cannon ball, the question arises as to what effect this would have on conceptual change. As well, the target in Simulation II seemed to provide a distraction from learning: participants spent more time trying to hit it by guessing at the input parameters rather than tying learning to the parameters. Simulation II had other characteristics that engaged the participants, such as the realism of the graphics, and the use of colour: it is possible that these other characteristics are enough to keep the engagement of students high while avoiding detracting from learning.

5.2 Conclusions

All of the participants showed a gain in concept map scores from pre-treatment to post-treatment, showing that there is a benefit to using simulations with science students, even in this un-guided way. The concepts learned by the participants related closely to the available variables in the simulations, and they were able to demonstrate conceptual change that exemplified higher cognition.

From the sample that this research is based on, it would seem that simulations with engaging characteristics, as they are defined in this paper, do not necessarily seem to promote conceptual change. While conceptual change is likely evidence of at least some level of engagement, engagement does not necessarily mean conceptual change is likely to occur. My results support the recommendations made by Sardone and Devlin-Scherer (2010) and Adams et al. (2008b), who suggest teachers keep this relationship of engagement and conceptual change in mind when considering simulations for their classes. While having engaged students is important, teachers should review the characteristics of simulations they are considering using and avoid choosing simulations that have features that may distract the student from the learning goals. These may inhibit conceptual change rather than promote it. I would also recommend that teachers consider administering an accompanying assessment tool to assist with the process. This tool could be a peer assessment to be administered while students are working in pairs; a discussion during and/or after use of the simulation; a worksheet or concept map; a journal or blog entry; and so on. This would ensure that the teacher can monitor whether the simulation is effective, and whether it is being effectively used. The results of these assessments can also be used in Zhou's argumentation model of teaching science for stimulating debate and provoking anomalous findings.

As our classrooms become more student-centred, and teachers' roles become less didactic and more facilitative, simulations will likely play a role in student learning. Although the students in this research formed somewhat superficial meanings, a teacher who is skilled at constructivist teaching and interested in providing opportunities for students to investigate concepts will be able to provide supplementary aid to students so that they can use the simulations more effectively. This also fosters opportunities for teachers to promote the growth of the 21st century skills of digital literacy, problem solving, critical thinking, and collaboration through the use of simulations and independent learning.

5.2.1 Suggested Uses for the Three Simulations

Each of these three simulations could have a place in a constructivist classroom. In chapter 1, I presented three guidelines for simulation use that Hennessy et al. (2007) suggested that lead to effective teaching and learning: allowing students to investigate the simulations themselves and explore “What if?” scenarios that are not the main focus of the lesson; pointing out imperfections or simplifications in the simulations and have students ponder them; and differentiating the simulations for more and less able students. This fits well with Zhou’s (2010) model where students are allowed to bring forward their pre-existing conceptions, and then through stages of debate and argument with the teacher, form more accurate conceptions using the simulations. During these stages, the teacher can use simulations to illustrate phenomena that are inconsistent with students’ conceptions in order to stimulate debate, and students can use the simulations to test hypotheses and demonstrate their own understandings. Based on the data that I observed in this research, I make the following suggestions on how to use these simulations.

Simulation I, with its simple interface and few controls can be used without supervision, and as such, it would be an excellent tool for students to use to review material after instruction. However, in order to promote motivation, I would suggest that students who use this simulation should be guided by a brief task list or set of questions to investigate. For example, one of the questions that could be provided to students to investigate is: is it possible for a projectile to travel the same horizontal distance when given the same initial speeds but different initial angles? This set of questions could be composed after an initial discussion of the concept being investigated so that the teacher can provoke anomalies and encourage conceptual change.

Simulation II is fun, and I believe it can better promote conceptual change than what the results of this research show. However, students would need to have a chance to use the simulation for a period of time before being expected to do a serious investigation. This would allow the student to get past the fun aspects of the simulation and on to being able to investigate motion with it. I would suggest that it be used as an introduction to projectile motion, much like it was here, but with guiding questions and the improvement noted in the next section.

Simulation III would be an excellent tool for demonstrations and for use within the context of Zhou's model. It also allows for differentiating between higher and lower functioning students because of the range of data that can be analysed. When a teacher or a higher level student manipulates the simulation, he or she can demonstrate many analyses of motion using the radio button features. This simulation could be used to model real-life data very easily, and having the ability to show the concepts of energy conservation and force vectors could lead to its use as a powerful demonstration tool. A possible activity would be to observe a video of a home run at a baseball game, take measurements from the video, and then re-create the ball's path using the simulation so that students could investigate energy, force, and air resistance. Once measurements have been taken, and the projectile's path initially modelled, many questions arise. Why isn't the flight path a parabola? Why does the ball seem to curve upward (backspin) at the beginning of the flight and fall sharply at the end (air resistance). This would take a great deal of work, but it would be a worthwhile project for both the teacher and the students. Again, it would be an excellent opportunity to use Zhou's model.

5.2.2 Possible Improvements to the Simulations

I would recommend improvements to Simulations II and III based on what I observed in this research. For Simulation II, I would recommend removing the control that allows the user to select different projectiles and provide the user with one projectile to conduct investigations with. This feature was determined to be disruptive, and changing it may improve learning. Simulation II also has limited display of data regarding the projectile's flight. I would recommend that the output of these data be made more apparent to the user, and that they only be displayed once the projectile has completed its path. For Simulation III, I would recommend improving its user-friendliness by allowing more than one projectile to be displayed. In its current state, the user must reset the simulation after each projectile is fired, and this was the cause of many other events in this research. I would suggest that the designer revisit the simulation and allow for multiple projectiles to be displayed.

5.2.3 Limitations of This Research

There are limitations to this research study that should be noted. First, the sample size was relatively small, and so the conclusions made may not be applicable to general cases of most students or most simulations. As well, during data collection, video equipment failed to fully record the actions of one of the participants, and so the sample size was reduced for some of the discussion to five participants rather than six. Although the sample size was small, it still satisfied the requirement to provide qualitative data on the cognitive models used by students when they use physics simulations, and provided answers for the primary and secondary research questions. A second limitation is that participants might not have given their best attempt at constructing the concept maps used as tools in this research. This limitation may relate to the fact that concept mapping takes time to learn, and the participants may not have learned the skill well enough to communicate their conceptual models. As well, since the data was collected outside of the classroom context, the students may not have provided their best effort. A third limitation is that the scoring rubric used in this research assumes that additions to concept maps are important, and it cannot account for conceptual change that occurs if a participant removes an invalid element by scratching it out. The participant would not be awarded any points for the original, invalid element, but its deletion likely represents conceptual change and should be credited in some way. The rubric is deficient in this area. A fourth limitation is the limitation of being able to identify the link between the use of a particular simulation and the conceptual changes made by the participants. This link is assumed due to the procedure of using different-coloured inks corresponding to different simulations for changes made to the concept maps. However, if the participant mistakenly used an incorrect colour, or if the participant used the information from a previous simulation combined with the current simulation, the conceptual change would have been attributed to the wrong simulation. A fifth limitation is that there was the possibility that a participant formed an invalid proposition simply because of difficulties or lack of familiarity with the scientific language, but there was not enough time to ask the participants probing questions about the terms and language they used on the their concept maps. As such, the concept maps were scored with few assumptions about what the participants meant, and the propositions were scored literally. Finally, there is the limitation of using indirect evidence of whether students were engaged by simulations such as access time, number of interactions recorded, and like-related interview responses. I have assumed that these were evidence of engagement for the purposes of this research.

Despite these limitations, this research has potential to add to the understanding of how simulations influence the conceptual models of physics students. By linking pedagogical theory – constructivism – with the use of digital learning objects – physics simulations – teachers may gain a better understanding of simulations in order to effectively choose simulations that encourage conceptual change in students.

5.3 Recommendations for Further Research

5.3.1 Expansion of this Design

It is likely that the inconclusive nature of some of the results from this research were due to the sample size of participants being so small. It would be worthwhile to take this design and apply it to a larger group of Science 10 students. Further, to ease the cognitive load of the participants and the workload of the researcher, I would suggest either trying to find students with an existing understanding of concept maps or spending more time instructing the participants how to use concept maps. As well, given the limitation expressed in this chapter that some parts of the concept maps might be scored invalid simply because of a student’s lack of familiarity with science language, it might be worthwhile to add a process to the method where the researcher or assistant could ask the students probing questions while they were constructing the concept maps in order to ensure the scoring was more accurate. Expanding on this idea and asking participants to describe their concept maps aloud might provide further clues to their conceptual understanding and any changes that had taken place. Another way to more efficiently gather data is to use an event logging application on the computers that the participants use, much like Cronje and Fouche did in their 2008 study. This would automate the process of coding and timing videos.

Simulation II seems to fit the requirements of much of the literature, and so might hold the most promise for improvement. A possible improvement to that simulation would be to limit the choices available in the projectile choice feature that distracted the participants, with the possible benefit of improved learning. Another suggestion would be to remove other components that distract, such as the statue and its associated animations. This is an area of suggested further research: does the removal of the distracting components of Simulation II still allow it to engage users effectively while improving its ability to effect conceptual change?

5.3.2 Other Questions to Explore

The pre-treatment concept maps hinted at the level of science achievement of the participants, but in a very limited way. There is a possibility that prior level of achievement also affects a student’s choice as to which simulation best suits him or her. Another area of suggested further research would be to enlarge the sample of participants and take into account their level of achievement in the previous science course. Does prior level of achievement affect how well a participant is able to construct meaning from using a simulation in an unguided way, and does this have an effect on which simulation allows for the most learning? A larger sample that takes into account prior level of achievement may inform the suggested uses of simulations with different characteristics by educators.

A second area to explore would be the possibilities of using simulations to assess science achievement. During this research, I often found that I was musing about the ways that these simulations could be used as both summative and formative assessment tools. While traditional assessments often require students to perform tasks on paper, it would be interesting to investigate whether simulations can more effectively and authentically measure student achievement.

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APPENDIX A

Interview Questions

1. Have you used simulations before?
    a. For what purpose? School? Games?
2. What parts of the simulations did you find helpful?
3. What parts of the simulations did you find confusing?
4. What did you dislike about using the simulations?
5. What did you like about using the simulations?
6. Which simulation did you like the most? Why?
7. Which simulation did you dislike the most? Why?
8. Did using the simulations cause you to think of questions that you would ask your teacher? What questions?
9. How would you improve the simulations?
10. What did you learn about projectile motion from using the simulations?
11. Can you think of another topic in school where a simulation would help? Can you be specific?
12. Would it be beneficial to you if your teachers used simulations more often?
13. Could simulations be used too often?
14. Could simulations replace teachers for some topics?

APPENDIX B

Credits

Simulation I

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URL:

http://galileo.phys.virginia.edu/classes/109N/more_stuff/Applets/ProjectileMotion/jarapplet.html

The rights of this simulation are stipulated in the GNU General Public License available at http://www.gnu.org/copyleft/gpl.html, and the uses of this software and images for the purposes of this thesis did not contravene that agreement.

Simulation II

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URL: http://phet.colorado.edu/sims/projectile-motion/projectile-motion_en.html

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Simulation III

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URL: http://www.walter-fendt.de/ph14e/projectile.htm

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