EFFECTIVE TEACHING STRATEGIES FOR PROMOTING CONCEPTUAL UNDERSTANDING IN SECONDARY SCIENCE EDUCATION

By

Emma Oliver

A Project Submitted to the Faculty of

The Evergreen State College

In Partial Fulfillment of the Requirements

for the degree

Master in Teaching

2007

This project for the Master in Teaching Degree

By

Emma Oliver

has been approved for
The Evergreen State College

by

____
Anita Lenges, Ph.D.

2007

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. Anita Lenges for her guidance and support throughout the learning and revision processes; her advice, encouragement, and ‘bumps’ have proved to be invaluable. I would also like to acknowledge and thank my parents, James and Judith Oliver, who read and edited many of my early drafts, and showed their support in countless other ways. These three people, along with my Son, and other peers, friends, family, and co-workers, gave me the confidence and encouragement I needed to complete this project with pride. I would also like to acknowledge The Evergreen State College for its dedication to student learning.

ABSTRACT

The inadequate academic science achievement is indicative of an education system that is failing to provide students with the education they will require in order to thrive in the coming decades. Developing a thorough understanding of science concepts in this age of rapid technological advances and economic change is essential. However, acquiring such an understanding within the United States public school setting requires effective pedagogical strategies that will promote such an understanding. In order to inform such a practice, this paper first examines the history of science education, followed by an investigation of viable pedagogical techniques used to promote conceptual understanding and intentional conceptual change learning in science education and possible impediments. A review if the literature indicates conceptual understanding in secondary science builds on students' prior knowledge, requires cognitive conflict, and occurs through conceptual change when learning is facilitated by instructional techniques for certain learning preferences and goals. Within conceptual change learning, several factors which may promote or impede conceptual change including group collaboration, students' ideas and explanations, students' beliefs about the nature of science (NOS), and motivation. Studies show effective pedagogic strategies to promote conceptual understanding build on student prior knowledge, encourage students' metacognitive development, provide students with relevant, meaningful, and interesting curricula centered around scientific concepts, which foster active student evaluation and investigation of scientific ideas.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

Students, as the future decision makers for the country, who have an understanding of the fundamental scientific concepts and their application will be capable of thoughtfully contributing to an increasingly complex technological society through informed decisions. This level of scientific understanding has been referred to as “scientific literacy”. Most educators agree science teaching and learning should move away from a system that promotes science primarily as recall of factual information and rote computation to one which emphasizes conceptual understanding and logical process skills. Support for such a reform has existed, to some extent, for much of science education's history. As the world becomes more technologically advanced, the need for science education programs that can meet the current societal demands grows. At the same time, the shortage of such programs becomes a hindrance to the advances this country can make towards a sustainable economy and environment. The inadequate academic science achievement is indicative of an education system that is failing to provide students with the education they will require in order to thrive in the coming decades.

Rationale

With the advent of the Internet, an infinite amount of information is at the fingertips of anyone willing and able to access it. However, much of this information goes unchecked. It is up to the consumer to discern innovative gadgets from over priced gimmicks, impending catastrophes from propaganda, and well-founded theories from fictitious tales. A conceptual understanding of scientific concepts can be an invaluable asset to anyone trying to rationally sort through the never-ending deluge of information, advertising, campaigning, and scare tactics infiltrating nearly all forms of media. Children and adults alike no longer have to go to the library or encyclopedia set to answer their curiosities in life. Now, many of them are just clicks away on their home computer. How difficult would it be to get a scientifically illiterate population to believe a false impending doom is coming? Remember Y2K? Much of the hype about the turn of the millennium had little to do with religious beliefs and a lot to do with a lack of scientific understanding.

On a more tragic scale, many deaths are caused by a lack of scientific understanding. For example, carbon monoxide poisoning has taken many lives during power outages simply because people are unaware of the danger and sources of this lethal gas. Speaking of lethal gases, greenhouse gases are accumulating at an unprecedented rate in our atmosphere. Even though many people believe greenhouse gases are bad for the environment, most of the population is unaware of what the major greenhouse gases are, let alone their sources. Without this knowledge, citizens are unable to make informed political, economic, and environmental decisions for a sustainable future.

There is little disagreement about the importance of developing a thorough understanding of science concepts in this age of rapid technological advances and economic change. However, the feasibility of acquiring such an understanding within the public school setting depends on effective pedagogical strategies that will promote such an understanding in the students of the United States. The most recent National Assessment of Educational Progress (NAEP) from 2005 shows eighth-grade public school students in the state of Washington made slight improvements as compared to results from 1996. The National Assessment of Educational Progress (NAEP) assesses science in two major dimensions: Fields of Science (Earth, Physical, and Life) and Knowing and Doing Science (Conceptual Understanding, Scientific Investigation, and Practical Reasoning). Out of a possible score of 300, the average scale score was 154. This was four points higher than in 1996 and seven points higher than the national average of 147. However, the percentage of students who performed at or above the NAEP Proficient level was only 33%. Although this is up from the dismal 27% who achieved this level in 1996, considerable gains still need to be made (NAEP—National Report Card, 2005).

Definitions

Conceptual understanding in its most basic form as defined by the NAEP (2005) means understanding the principles of science used to explain and predict observations of the natural world and knowing how to apply this understanding efficiently in the design and execution of scientific investigations and in practical reasoning. In assessing conceptual understanding and its application, the NAEP measures students' ability to apply facts and events learned from science instruction and from personal experiences with the natural environment, and their ability to use scientific concepts, principles, laws, and theories that scientists use to explain and predict observations from the natural world. In addition, students should be able to use information about procedures for conducting scientific inquiries based on propositions about the nature, history, and philosophy of science. Finally, students should also be aware of the kinds of interactions between and among science, technology, and society (NAEP, 2005).

Conceptual understanding has also been defined in *How Kids Learn Science*

(2005) as the organization of knowledge around core concepts. Girad and Wong (2002) state conceptual understanding requires both knowledge of and the ability to use scientific concepts to develop mental models about the way the world operates in accordance with current scientific theory. The American Association for the Advancement of Science (AAAS) equates conceptual understanding with scientific literacy and believes it to entail the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity (Project 2061 – AAAS, 1993).

A composite of these definitions is used to define conceptual understanding in this paper. This composite was chosen to best represent how conceptual understanding is described in the research literature. Conceptual understanding is the ability to understand, communicate, and apply fundamental and broad scientific laws, theories, principles and concepts in order to make well-informed decisions in an increasingly complex technological society.

Limitations

This definition is generally restricted to the products, rather than the process, of scientific knowledge. However this definition does not try to argue a separation between scientific products and processes. It simply emphasizes the former. In the literature review, student conceptual change, motivation, beliefs on the nature of science, methods of investigations, and communication techniques will be examined in relation to the development of conceptual understanding.

Statement of Purpose

Most science education standards state or imply that conceptual understanding is a major goal. This goal is often embedded within and underlies other goals such as scientific literacy. For example, AAAS has defined scientific literacy as the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity (Project 2061 – AAAS, 1993). Other science education advocates expect students to be able to use unifying scientific concepts and processes (NRC, 1996), and to demonstrate knowledge and application of core scientific concepts and principles (OSPI, 2005).

Educators must help students build a conceptual understanding through implementing teaching and learning techniques that will engage students' interest, build on students' knowledge and experiences, facilitate intentional conceptual change, foster an investigative, meaningful approach to learning, and guide students towards meeting and exceeding state and national mandated educational goals.

In order to inform such a practice, this paper will examine research studies conducted on pedagogical techniques that have been used to promote conceptual understanding in science education, factors which may impede such an understanding, and ways to encourage intentional conceptual change.

Promoting students' conceptual understanding has long been one of the most important goals for science education. However, this goal has not been easily attainable. The reasons for such difficulty are still unclear. Cognitive psychologists have spent the last several decades exploring pedagogical techniques that enhance students' learning.

Numerous researchers (Bliss and Ogborn, 1994; Caravita and Halldén, 1994; Chi et al., 1994; de Leeuw & Chi, 2003; Jonassen et al., 2005; Niaz, 2002; Park and Han, 2002; Tiberghien, 1994; Vosniadou, 1994) have noticed students often have a difficult time reconciling their everyday conceptions with scientific conceptions. David Ausubel (2000) was one of the first to emphasize and study the role of students' prior knowledge in meaningful learning in the 1960s. He distinguished meaningful learning from rote learning in terms of associations made (in the case of meaningful learning) with ideas or concepts in the learner's cognitive structure. He believed concept learning consisted of first concept formation, and second concept assimilation. He believed most concept formation occurred in the early years of life through direct experience with the natural world.

Following concept formation, concept assimilation occurred if critical attributes of new concepts were anchored to existing concepts in either a subsumptive or superordinate manner. In this sense concepts form the building blocks from which meaningful learning and problem solving abilities grow. When students learn by rote memorization, Ausubel (2000) argued, no such connections are made. It is the association of new ideas with students' prior knowledge or schema which make for meaningful, and thus more stable, useful, and accessible, learning.

Ausubel (2000) believed students needed the teacher to explicitly state such connections through direct verbal teaching. This was in contrast to discovery learning, another emerging instructional method at the time, which encouraged students to build their understanding inductively from hands-on experience. Ausubel did not believe direct teaching should consist of the teacher reading from the text and students memorizing what was said. He believed the teacher could make the material relevant to the students' prior knowledge by carefully selecting and ordering the material to be learned in a logical fashion, preferably one that parallels both the existing cognitive structure and the developmental changes in the organization of the students' conceptual understanding. He believed students learn best when curriculum is structured from the broad principles, down to the smaller details. Advance organizers are an instructional tool that helps students to organize these ideas and make explicit connections between the students' relevant prior knowledge and the new information. In addition to organizing information, advance organizers also made learning an active process for students. Ausubel (2000) believed learning must be an active process for students, which required distinguishing relevant from irrelevant material, and resolving contradictions between new and established concepts. The teacher also must adjust the learning material to suit the backgrounds and abilities of the learners.

Joseph Novak built on Ausubel's ideas and has done considerable research on students' use of concept maps, a type of advance organizer, to develop conceptual understanding in science education (Novak, 1995; Wandersee et al., 1994). Researchers (Case & Gunstone, 2002; Jonassen et al., 2005; Pendley et al., 1994; Regis et al., 1996) have also studied the use of concept maps in eliciting students' prior knowledge and conceptions, and as a metacognitive tool for students to use in monitoring their learning. Ausubel believed acquiring such knowledge is the most important information for a teacher to have prior to instruction.

Another tool used to elicit prior knowledge is open-ended questioning. This may be done through discussion (Asoko, 2002; Bell, 2005; Hammer & Elby, 2003; Coll & France, 2005; Geelan et al., 2004; Pugh, 2002; Swafford & Bryan, 2000; Tao, 2001; vanZee & Minstrell, 1997; Yip, 2004) or in written form (Cavallo, 2003; Fellows, 1994). Once students’ prior knowledge, conceptions, and misconceptions are established, cognitive conflict (de Leeuw & Chi, 2003; Jonassen et al., 2005; Niaz, 2002; Park & Han, 2002) has been used to guide students to scientific understandings.

There is some debate as to whether students come to conceptual understanding through the enrichment of cognitive structures, the transformation of such structures, or a combination (Vosniadou, 1994). The transformation of cognitive structures is believed to occur through conceptual change (Andre & Windschitl, 2003; Asoko, 2002; Bell, 2005; Bliss & Ogborn, 1994; Caravita & Hallden, 1994; Chi et al., 1994; Dalton et al., 1997; deLeeuw et al, 2003; deVries et al., 2002; diSessa et al., 2003; Duit & Treagust, 2005; Ferrari & Elik, 2003; Hatano & Inagaki, 2003; Hennessey, 2003; Hynd, 2003; Jonassen et al., 2005; Linnenbrink & Pintrich, 2003; Luque, 2003; Mason, 2003; Niaz, 2002; Pintrich et al., 1993; Qian & Alvermann, 2000; Sinatra & Pintrich, 2003; Southerland & Sinatra, 2003; Swafford & Bryan, 2000; Thagard & Zhu, 2003; Tiberghien, 1994; Tsai, 2000; Vosniadou, 2003; Vosniadou, 1994; Wandersee et al.,1994; Yip, 2004.). Vosniadou (2003) stated conceptual change is the outcome of students restructuring their everyday, naïve theories into scientifically based theories. She argued conceptual change is a slow, gradual process that may occur without intentional learning. However, this type of conceptual change is unstable because students often retain internal inconsistencies. They are often unaware of these inconsistencies because the conceptual change did not incorporate the metaconceptual awareness that helps students to realize these inconsistencies exist.

Sinatra and Pintrich (2003) believed intentional conceptual change, is most effective in developing stable conceptual understandings. Intentional conceptual change requires "goal-directed conscious initiation and regulation of cognitive, metacognitive, and motivational processes to bring about change in knowledge" (Sinatra & Pintrich, 2003, p.6). Pintrich and Sinatra have studied many factors that may impede or promote intentional conceptual change learning. Mechanisms of conceptual change include cognitive and metacognitive processes (de Leeuw & Chi, 2003; Ferrari & Elik, 2003; Hennessy, 2003; Luque, 2003; Thagard & Zhu; 2003) including self-regulation, self-explanation, and metacognitive control. The mechanisms may be affected by epistemological, social and motivational determinants (Andre & Windschitl, 2003; diSessa et al., 2003; Hynd, 2003; Linnenbrink & Pintrich, 2003; Mason, 2003; Southerland & Sinatra, 2003) such as student beliefs, attitudes, emotions, goals, interests, and dispositions.

Summary

Developing a conceptual understanding in secondary science is an important but complex endeavor for both teachers and students. The current research moves beyond curriculum design to additionally focus on the mechanisms and determinants of students' cognitive processes. There is evidence that public school students in American science education can achieve such an understanding. This evidence will be examined in the literature review, following the chapter on history of science education in the US. The paper will then turn to a discussion of classroom implications that were gleaned from the review of the literature. Finally the paper will conclude by identifying possible areas of future research that could help educators increase students' conceptual understanding.

Vosnaidou (2003) conceded intentional conceptual change learning goes beyond the requirements of school tasks. Possibly this is a shortcoming of the schools' expectations rather than too much to ask of students and teachers. As technology increases, so do the science learning expectations of future generations. If methods to help students learn more information, in a stable, accessible, and most importantly, enjoyable fashion exist, these must be implemented to the best of our ability in the classroom.

Science learning today has emerged from a history of reforms and paradigms. The following chapter will examine the history of science education, primarily at the secondary level, in order to better understand the events and developments that have shaped science education today. The chapter will proceed chronologically, starting in the mid eighteenth century when formal science education in the United States began to get established. The chapter proceeds to the present as science education continues to adapt to the new capabilities students will need to intelligently participate in today's society.

CHAPTER 2: HISTORICAL BACKGROUND

The history of science education in the United States includes several paradigm shifts between academism, practicalism and reformism. Early advantages thought to come from science education were republican idealism, pastoralism, and pragmatic, national, and moral advantages. The different educational philosophies each sought different goals in using the advantages of science education, which resulted in different educational strategies. A continuum with two major extremes resulted. On one end of the continuum is a science education designed to appeal to the greatest numbers of students with curriculum that uses science applications to connect science with students' everyday lives and interests. To the other extreme is a science education based solely on theoretical concepts, often isolated from the contexts in which they are used or were discovered, in hopes of preparing students for an increasingly competitive, technological society. In between these extremes, many reform movements have hoped to stake claim on some middle ground. The following chapter will highlight many of the philosophical shifts in science education and the resulting classroom implications from 1749 through the present.

Schools for a New Republic

Benjamin Franklin was one of the earliest proponents for science education in America. Franklin's Public Academies, the first of which opened in Philadelphia in 1749, emphasized a pure and useful education including science. He believed such an education would lead to personal, and therefore social, improvement. Thomas Jefferson, seventy years later, also emphasized science education in his curriculum for the University of Virginia in 1818. Science, Jefferson maintained, as a combination of intellectual, moral, and spiritual methodologies, represented the Enlightenment ideal, whose ultimate goal was nothing less than the perfecting of both individuals and society as a whole. Jefferson put science education on the center stage; he believed freedom could qualify as “the first born daughter of science” (Montgomery, 1994).

Enlightenment and usefulness came to be attached to an enormous range of republican virtues and values, and set the stage for the basic scheme of debate over science education even to the present. Science was thought to offer five noteworthy principle advantages. These included pragmatic advantage, national advantage, moral advantage, republican idealism, and pastoralism. Pragmatic advantage asserted learning science, in terms of Franklin's “useful arts,” would improve individual and collective productivity and wealth, first for agriculture and later for manufacturing. John Adams advocated for science education on the basis of it providing the fundamental virtues of the work ethic needed in America's current and future economy. National advantage was thought to be gained through the training of engineers, architects, inventors, and industrialists which would release America from its reliance on former expertise and goods, and provide national economic independence. Honesty, patience, discipline observation, civility, and industriousness were thought top be enhanced by science and thus provide a moral advantage. Republican idealism, a result of Enlightenment belief, thought science could bring about revolution and end the prejudices and tyranny of the past through openness, and exploration. Pastoralism believed the study of American nature would lead one to discover the uniquely American values and virtues available only on the face this land, which was chosen by God. In general all those who advocated for science education had a common goal of preventing the deterioration of character, learning, or nationhood. Science was to bring to America what Europe could not—freedom, reason, and genius (Montgomery, 1994).

Education: What and for Whom?

These principle advantages guided educational policy into three traditions: academism, practicalism, and reformism. Academism discouraged the questioning of authority, curriculum was seen as the ultimate authority, and the teacher was sometimes reduced to a messenger. Practicalism advocated for education that was directly connected with the ordinary needs of society. In contrast to the academist view of education as a way of maintaining class divides, practicalism advocated for training for the working- and middle- classes which would lead to economic opportunity and the possibility for upward mobility. Reformism, whose most prominent spokesperson was John Dewey, aimed for a more democratic way of life through connecting everyday life with classroom life.

The ideal individual educated within the "liberal arts" was someone who used language to demonstrate maximum power and leadership in art and politics. Language was seen as the main instrument for power, for this reason, science was given a secondary role in education. Science was forced to grow outside of the university system. It was through this complete removal from the rest of university educational environment that scientists claimed to have a higher truth through disinterest and objectivity. Only then was acceptance slowly forthcoming. It wasn't until after the American Revolution and into the 1820s when early colonial colleges began to establish and broaden "pure" science courses (Montgomery, 1994).

Eighteenth and nineteenth-century technological developments brought to light the need of preparing students for a changing world. Early developments included steam power, railroads, and textile advancements such as the cotton gin, dyes, and sewing machines. Later came radioactive emissions, combustion engines, and medical advancements such as vaccines. These advancements required a new way of thinking to understand and control the powers of nature. Students needed a broad and practical education to equip them for their world. (DeBoer, 1991). Practicalism popularized the notion of learning as a source of practical advancement, whether for the nation, for industry, or the individual. This approach was based largely on Franklin's idea that education should be connected with the life and needs of ordinary society (Montgomery, 1994).

Reformers, a Diverse Lot

The academism education of the eighteenth-century had focused on the past and included studying Greek mythology, Greek, Latin, reading, writing, and arithmetic. The main goal of education was to develop mental abilities (DeBoer, 1991). Through the first half of the nineteenth-century, school reformers such as Josiah Holbrook, Stephen Simpson, Henry Barnard, James Carter, and Horace Mann battled for what would be called the common school movement in which a public system of education would be open to all, for the purposes of civic betterment and the creation of future generations founded on a “sharing of values” (Montgomery, 1994).

Proponents of science education during the nineteenth-century such as Youmans, Huxley, and Spencer (DeBoer, 1991) argued science develops a broad range of mental abilities including independent judgment and inductive thought. These men built upon the ideas of Thomas Jefferson who believed the battle against tyranny could be waged through learning. These ideas were later supported by the work of John Dewey and the tradition of education as reformism. Reformism views education as a never ending process without any necessary aim toward specific practical gain other than a more democratic way of life (Montgomery, 1994).

Academism, practicalism, and reformism traditions have a complex and interwoven history with theorists using ideas from the popular tradition as the fuel for change towards a different tradition. For instance, Youmans reasoned that science consists of many organized facts which produce generalizations that are easier to remember and can be applied to everyday thinking through inductive reasoning. He also believed the mind worked by organizing sense impressions, or neuronal structures as we call them today. Youmans contrasted scientific reasoning to that required in math, and declared mathematics required only deductive reasoning. He viewed science education as an important tool to strengthen mental intellect through inductive thought by weighing evidence and determining what is relevant and what is not (DeBoer, 1991). Youmans combined the academist view of education for the development of intellect with the reformist desire for independent judgment.

In Huxley's view, physical science forces upon us conceptions of the universe, thereby molding our theory of the universe. Huxley believed science could compete with the great works of the Greeks and would eventually influence medicine, engineering, and the clergy. He believed science should be learned through a combination of observation and study, where the lab is used to develop clear and definite conceptions through first hand observations (DeBoer, 1991).

Another proponent for science education was Spencer, who believed science education was needed for modern manufacturing, steam engine development, smelting, the arts, and child rearing. Spencer argued an evolutionary development of all institutions reflected a change in authority of both politicians and the clergy. Therefore, education should focus on personal understanding, meaning, and freedom, rather than rote memory (DeBoer, 1991). Spencer's philosophy on science education during the 1860s maintained children should be told as little as possible, and induced to discover as much as possible. This would allow the natural process of individual evolution to take place.

However, Spencer came from an academist view and believed science was the realm of absolute truth and heroic truth seeking. He also argued, on the basis of social Darwinism, economic divisions were natural and the mechanisms for such were fixed and certain. Thus, education had to be seen as a way to maintain partition between social classes and to make persons adapt to their true station in life. Learning science would aid in such understanding and adaptation. It would teach the necessity of the social order and would thus help the lower classes "prepare for life" (Montgomery, 1994).

Spencer and Huxley were heavily influenced by the ideas of Pestalozzi, who had been influenced by Rousseau. Pestalozzi advocated an education based on sense impression, reasoning, and experimentation, which worked in harmony with the natural development of the child's mental faculties. In 1860, Pestalozzi and his followers argued that science education was an active process where concepts were introduced through the study of natural objects. This new way of teaching and learning required the teacher to have greater subject matter knowledge, and knowledge of child development in order to choose appropriate materials and manage the variety of interactions in the classroom

(DeBoer, 1991).

Following the influence of Pestalozzi, was that of Herbart from Germany in the 1890s. Herbart believed the “mind was a set of ideas or concepts that were built upon each other and richly interconnected”. From this theory of mind follows the purpose of instruction and education to be the construction for each person this arrangement of ideas. The purpose of education was not just to exercise the mind but also to enable a person to live a well-rounded, moral life. Herbart began with the sense of perception rather than inherited biological capacity for the development of mind. Only concepts that could be used by a broadly functioning person should be used in curriculum. He believed all knowledge must be acquired by the individual. Thus, the capacity to learn was correlated with a person's efforts and was continuous, theoretically without bounds. This contradicted Spencer's social Darwinism and the traditional notion that the purpose of education was to develop mental faculties by exercising mental abilities without regard to content (DeBoer, 1991).

Herbart brought to light one of the most revolutionary ideas on science teaching and learning—capturing the students interest first will help students use instruction to build conceptual understanding. Herbart's four-step model, of teaching, similar to those currently used, included theory of interest, theory of concept formation, direct instruction, and application. Herbart also contributed a systematic approach to educational thought and curriculum design in general (DeBoer, 1991; Montgomery, 1994).

Herbart's theory of interest stated that for instruction to be effective, the pupil's interest must first be gained. In his theory, interest came from either experience with the natural world or social interaction. Experiences with the natural world were the starting point from which the teacher should build conceptual understanding. Concept formation, Herbart theorized, is built from direct and indirect perceptions by association with organized generalizations or principles. The role of the teacher was to begin with the student's prior knowledge and add groups of ideas associated strongly and united logically. The teacher was not to present the child with new information that could not be linked in this manner. New conceptions should be developed inductively. The student could discover the relationships between natural phenomena through teacher questioning, guidance, informal conversation with the teacher and peers, and experience with the natural world. After the pupils were given first hand experience with the subject matter and time to puzzle through their conceptions, the teacher would systematically and enthusiastically explain ideas the pupil could not discover alone. The final step in Herbart's instructional method was to have students demonstrate their knowledge by application, such as solving problems, writing compositions, or performing other tasks that depended on the acquired knowledge (DeBoer, 1991).

Building on the ideas of Rousseau, Pestalozzi, and Herbart, child-centered education became popular in the late nineteenth- and early twentieth- centuries. Teaching as a process of facilitating learning by bringing meaning through objects and words in a way that was pleasurable to the child gained momentum rapidly as John Dewey and William James spread the new orthodoxy to educators around the country. In 1896, Dewey founded his famous Laboratory school in order to put into practice his idea that a public school should be "a model home, a complete community and embryonic democracy" (DeBoer, 1991; Montgomery, 1994).

Poorly Implemented Reforms

The new theories and innovative methods (field trips, group learning, and individual laboratory work) excited many professional educators. However, the new theories and methods were only sporadically implemented in the classrooms. When they were confronted with performance evaluation by standardized assessment, teachers and administrators reverted to using old forms of learning by recitation (Montgomery, 1994).

Even though these ideas of Herbart, Pestalozzi, Spencer, and Huxley were popular in educational literature and conferences, the methods were not reflected in the teaching practices of most American schools. J.M. Rice and Charles Eliot made similar observations in American schools during the 1890s. Rice found the spirit from education reform ideas was often lost when implemented in the classrooms. Although teachers were using manipulatives and other sense training in their classrooms, many were still not permitting children to think and develop naturally in all their intellectual, moral, and physical faculties. All the children's knowledge was still memorized from texts. As an example of an inappropriate lesson, he observed a student to “call off, in rapid succession, more diseases than are known to most physicians.” Active thought was absent in most of the classrooms in major cities throughout the country. Rice described those schools using a modernized approach to education as warm, happy, and beautiful, and a place where children were guided to observe and think (DeBoer, 1991).

In 1890 Charles Eliot reported to the Massachusetts Teacher's Association that schools were teaching science by using through dull, overly complicated texts that lacked human interest. He believed that science should be taught by incorporating students' sense of sight and touch through direct study of the physical world. Eliot believed learning science could develop disciplined observation, inductive faculty, sober imagination, and sincere, appropriate judgment when the work is interesting, and when the children are given a sense of success. Eliot observed that science teaching methods then in use, neither developed the power of thought students needed, nor empowered them for useful action in their lives. He believed that any worthy education should focus on organizing knowledge from direct contact with the physical world. It should develop an appreciation of beauty, a love of learning, and a sense of honor and duty. Eliot believed these components of a quality education, should be directed toward what he thought of as the primary goal of education-- personal empowerment (DeBoer, 1991; Montgomery, 1994).

Thanks to the Herbartians, Eliot, Spencer, Rice, and Dewey, by the middle of the twentieth century, practicalism began to override academism. Lab-based instruction increased and was aimed at meaningful understanding which was applicable and relevant to students' everyday lives. This change to practicalism was led by the need to make learning science useful for all students, not just those attending college. In the 19th century, Spencer had advocated for personal utility. By the twentieth century, he stressed social utility, aimed at control and efficiency, and believed this could be attained through education (DeBoer, 1991; Montgomery, 1994).

Progressive Goals and a Conservative Critique

Five major goals for science education were established in 1920 by a report from the science committee of the Commission on the Reorganization of Secondary Education (CRSE) entitled *Reorganization of Science in Secondary Schools.* These were: 1) to improve the welfare of society, 2) to develop an avocational interest in science, 3) to develop interest for further vocational study, 4) to develop the ability to observe, measure, classify, and reason clearly, and 5) finally to develop a full understanding of the principles of each science field. The final goal was to develop teaching strategies to meet these goals. Theories, laws and generalizations must not be taught in isolation as meaningless abstractions to be memorized. Instead, the principles of each science field were to be taught and understood in terms of logical, scientific, and socially relevant applications. As a way of organizing curriculum, members of the science subcommittees recommended that teachers include broad-based, interesting, and unifying themes or topics that enhanced learning by the use of projects or problems that were real to students. The second recommendation was to use the laboratory to apply the scientific method to interesting problems and to motivate students. Hands on experience and relevant past and future application were believed to be the keys to learning science (DeBoer, 1991).

Progressive education, based largely on a combination of practicalism and reformism, dominated the first half of the twentieth-century. Education during this time was based on the premise that a good education should be oriented toward the everyday activities of students and that it should prepare students for life in society. Democratic living, personal and social growth, and human relationships were considered more important for most of the students than were the traditional subjects of science, mathematics, English, history, and languages (DeBoer, 1991).

In the seven years between 1940 and 1947 the enrollment in higher education had tripled from 750,000 to 2.3 million. This was largely due to passing of the GI Bill in 1940. Early on, conservatives hoped the influx of students would subside and higher education would return to its elitist roots. However, when this didn't happen, they became concerned with the dilution of higher educational quality. Veterans were academically performing better than expected and conservatives used this to argue education standards were too low. College introductory science classes became larger, more anonymous, and less interactive. This resulted in these classes becoming a tool to weed out those students who did not possess the motivation, professional ambition, and higher ability to succeed in college (Montgomery, 1994).

Attacks and the Return of Academism

During the 1950s, as American schooling began to appear less and less academically rigorous, attacks were waged on the system. The launch of Sputnik in 1957 added further concern for the quality of American schooling. Bestor believed schools were the only institutions that society could count on to furnish intellectual training. The primary job of schools was the deliberate training of disciplined intelligence. Such ideals marked the return of academism to American schooling (DeBoer, 1991; Montgomery, 1994).

In 1950, Ralph Tyler proposed a framework for curriculum design in which the answers to four fundamental questions would serve as a guide. The questions were: What educational purposes should the school attain now? What experiences can it offer to achieve these? How can these experiences be organized? How can one evaluate success? Student behavior, rather than cognitive ability, would serve as the barometer of educational success. Tyler's general scheme came to be adopted as doctrine by most secondary educators from the 50s through the 80s. By the mid 1970s, concerns for basic skills, test scores, and minimum competencies, had replaced progressive, open classroom agendas (Montgomery, 1994).

During the cold war, faith in science as objective and without interest in culture was diminished. Science now carried with it the use of the atomic bomb, initiation of the arms race, and nuclear terror. The scientific approach or attitude was no longer the moral high ground. Racism, Stalinism, and the WWII cast doubt upon the value of scientific expertise. Higher ideals were needed if American education was to provide the sensibility to use the power of knowledge for the good of all. The liberal arts picked up where science fell short as the method of providing the educated expert a broad, yet structured, foundation that would help students not lose sight of a greater mission. Science hadn't lost its prestige or interest gained through technological developments, but never again would the scientific mind be the sole source of hope for a better world. The desire to control science and simultaneously to build America’s national scientific enterprise shifted science education back toward an academist tradition. This shift updated the old system of mental faculties in terms of such categories as effective thinking, communication abilities, relevant judgments skills, and discrimination among values. These traits of mind favored the humanities as the area to judge, appraise, and criticize, whereas the sciences were the place to analyze, describe, and explain (Montgomery, 1994).

Searching for a Better Way

In 1956 Jerold Zacharias joined the Massachusetts Institute of Technology to revise science and physics curriculum by organizing them around central concepts of the organized disciplines, thus focusing student understanding on the nature of the disciplines. Thinking logically and conceptually was emphasized over technological applications. The new texts of the 1960s attempted to accomplish these goals by telling a story that was interesting, conceptually integrated, and based on experimental evidence (DeBoer, 1991).

In 1959, a group of 35 scientists and educators headed by Jerome Bruner met to discuss the new developments in science and mathematics teaching and to offer guidance for future developments in these areas. The emphasis on teaching the structure and fundamental principles of the science disciplines as early as possible was of particular interest to the committee. Learning science in this way included not only the principles of the field, but also how the attitudes of scientific investigation and spirit of discovery contribute to the essence of the subject. Bruner believed learning is more relevant, applicable, and memorable for students, if they understand the ideas and relationships of the subject matter. He also believed discovery learning helps students to be active learners by encouraging them to think inductively and to use examples to form general principles. This way of teaching provided students ideas that could be fit into a pattern that allowed for better comprehension and retention (Glenn and Duit 1995; DeBoer 1991).

Bruner's ultimate goal was to make college level work teachable at lower grades. Bruner believed this goal could only be achieved with the active participation in educational reform of the best scientists and scholars. Control over curriculum design was shifted from the hands of educators to those of scientists. The resulting curriculum presented the process of science as fixed and given, without the opportunity for students to discover the process. This curriculum also detached science from outside influences and put the individual on the center stage rather than presenting the reality of teamwork in present in research settings. Curriculum designers attempted to make it teacher-proof to ensure that lessons went as the scientists had planned. Experiments previously studied at the college level were pushed down to the high school, junior high and even grade school levels (Montgomery, 1994).

. Bruner also introduced the work of Jean Piaget and the idea of stages of mental development to science education. Through the application of Piaget's work to science teaching and learning in the classroom, he believed the key to successful science learning was to translate materials into logical form that the developing child could understand and to present these materials in a way that was consistent with the child's level of intellectual development. This view of science learning advocated teaching the basic principles of science beginning in elementary school and to redevelop important topics in later years with increasing abstraction. Bruner termed this method “spiral curriculum” (DeBoer, 1991).

As students struggled with spending a great deal of effort in the programmed science study on trying to discover the unwritten rules from centuries of scientific knowledge, the excitement and desire to learn turned to cynicism within teachers and students alike. By the 1960s, the scientists had relinquished control over curriculum in pursuit of other interests. A new rationale for designing science curriculum began to emerge in which education would study itself (Montgomery, 1994).

Still Searching

In the late 1960s, the National Science Foundation shifted its focus from science for scientists to science for citizens. Better science understanding was hoped to create a more favorable view of science by organizing curriculum around finding solutions to practical problems rather than seeing technology as the problem (Montgomery, 1994).

As the popularity of teaching for social utility rose again, curriculum reform was again brought to the forefront. Hofstein and Yager (1982, cited in DeBoer, 1991) argued science curriculum should be organized around social issues rather than the concepts of the disciplines. This began a heated debate in the science education field. Even if such a reformed curriculum were to arouse student interest and allow for teaching of analytical skills and terminology, it would be unable to convey any real understanding of structural integrity of science (Stinner, 1995).

Most science educators could agree the scientific process places foremost importance on sense impressions as the source of raw data about the world upon which our scientific knowledge builds. The data are systematically organized into categories, the organized data lead to inferences, the inductive inferences are tested, and conclusions are drawn. Kuhn, Feyerabend, and Toulmin questioned the appropriateness of portraying the scientist as a coldly rational inductive empiricist. Kuhn was also concerned about how students learn concepts in science education and the relationship between what may be called the logical plane of activity and the evidential plane of activity. He believed scientists learn through a study of the application of a theory to some concrete range of natural phenomena, and never learn concepts, laws, and theories in the abstract and by themselves (Stinner, 1995; Montgomery, 1994). These theorists showed how scientists have engaged in science activities as human participants and not as completely objective and detached observers. This moved the view of the scientific process from one of cumulative recordings of observations to a revisionary one. Stinner (1995) argued that in order for a student to learn through a revisionary process, the psychological plane of activity, in addition to the logical and evidential planes of activity, must also be attended to. Stinner created the "LEP" conceptual model to help teachers attend to the logical, evidential, and psychological planes. These planes are generally left up to the teacher to incorporate and guidance is not generally found in the curriculum.

Conceptualizing Concepts

In order to revise, Freundlich (1978, cited in DeBoer, 1991) argued, adequate conceptual background knowledge must be possessed; without this knowledge, it is unlikely a child will inductively discover even the most basic concepts of science. A goal of science educators has always been to have students understand the products of science and thereby gain a conceptual understanding of science, even though separating scientific products from their process is somewhat artificial. There were a number of opinions as to how a conceptual understanding was developed. Theorists such as David Ausubel believed direct didactic instruction could modify old conceptual structures to accept and assimilate new concepts through direct and orderly presentations for the students to learn through reception (DeBoer, 1991; Novak, 1995). Ausubel also employed advance organizers and Socratic questioning to create a learning environment in which teaching and learning are active processes (Glynn and Duit, 1995). Joseph Novak was the major advocate of Ausubelian theory as applied to science education. He defined reception learning as a form of learning in which concept the teacher explicitly teaches labels and the regularities they represent. This directly contrasts with discovery learning in which regularities are discovered by the learner. However, Novak did insist that the concepts had to be meaningful to the students. This required the learning material to be conceptually clear and presented with language and examples relatable to the learner's prior knowledge. The learner was encouraged to process prior knowledge and to choose to learn meaningfully. Meaning was to come from connections with prior knowledge, through deductive reasoning from general principles to examples, and thus what the learner already knows became the single most important factor influencing learning (DeBoer, 1991; Novak, 1995) and the learner's motivation (Novak, 1995).

As cognitive structures become more complex, students are able to solve increasingly complex problems and to acquire more in-depth knowledge about a concept. This Ausubelian theory relies on the direct teaching of organized principles, advanced organizers, and concept maps. Concept maps were developed as an instructional tool to help students make explicit connections between concepts. These organizers were in preference to students constructing knowledge through inductive reasoning and discrete interactions with related materials. Ausubel also believed secondary students who had learned a sufficient number of basic concepts would be better served by learning through verbal instruction rather than cookbook laboratory exercises (DeBoer, 1991; Novak, 1995).

Ausubel and Novak also suggested student motivation for conceptual change is best controlled through evaluation strategies which discourage rote learning of verbatim statements, definitions, or descriptions. They argued that rote learning impedes assimilation of new knowledge into existing frameworks. Concept maps could be used not only as a learning tool but also as a formative and summative evaluation tool. In addition to employing concept maps to help students organize concepts in a hierarchical fashion, Ausubel and Novak believed students should also be taught about brain mechanisms and knowledge organization. This was thought to help students who are accustomed to rote learning develop new learning modes, more conducive to conceptual change learning (Novak, 1995).

Another direct instruction approach to concept learning and hierarchical learning came from Robert Gagne. Like Ausubel's reception learning, hierarchical learning was identified in 1979 as one of the major research paradigms in science education. Gagne believed learning to be a cumulative process, based on conditions of learning. Therefore, students should be taught by breaking down learning material into small segments, arranged sequentially, and directly taught. The conditions for learning also required teachers to motivate students, direct students' attention, activate prior knowledge, elicit performance, and clearly state objectives. Lessons utilized repetition, reinforcements, providing feedback, and attention to sequence (DeBoer, 1991; Glynn & Duit, 1995).

Wittrock (1992 in Glynn & Duit, 1995) believed learning involves generating an understanding through constructing relationships between prior knowledge and new information through attention and motivation. On the other hand, Posner maintained conceptual change occurs when a student is willing to change his or her mind through the process of accommodation. This would occur when dissatisfaction with existing conceptions developed—cognitive conflict, a new conception was intelligible, initially plausible, and suggested the possibility of a fruitful research program (Glynn & Duit, 1995).

Instructional teaching strategies which are less teacher centered have also been introduced. One such strategy in science education was the learning cycle based on Piaget's intellectual development process and developed by Robert Karplus in 1977 (DeBoer, 1991). Piaget suggested that cognitive development is a function of four processes. The first three are physiological development, personal interaction with one's environment, and social transmission or direct instruction. The fourth process Piaget called “self regulation,” the process by which an individual is first faced with new knowledge and subsequently transforms this new knowledge to fit into existing mental structures through accommodation or assimilation. This generally occurs when cognitive conflict or disequilibrium provides the energy for reorganization of mental structures to take place. Karplus' learning cycle consists of three instructional phases—exploration, concept introduction, and concept application in order to combine experience with social transmission. During exploration, students learn through their own actions and reactions while interacting with the environment. Minimal guidance is given during this phase. The experience should raise questions or complexities they cannot solve with their accustomed patterns of reasoning. This gives the disequilibrium the student needed to prepare for self regulation. The second phase, concept introduction, starts with the definition of a new concept or principle that helps the students apply a new pattern of reasoning to their experiences. The concept may be introduced through any teacher planned or organized activity such as lecture, film, demonstration, or text. This step should always relate to the exploration activities to help students make connections between concepts and observations. The final step in Karplus' learning cycle is concept application. During this step students familiarize themselves with the new concept or reasoning pattern as they apply it to new contexts. The second and last steps in the learning cycle are aligned with Ausubel's method of direct instruction and increasing conceptual understanding by connecting networks of ideas through interactions with a variety of contexts. It differs from Ausubel’s method with the teacher explicitly providing an opportunity for disequilibrium, as Piaget suggests, prior to the introduction of the concept (DeBoer, 1991).

Teaching through inquiry has also been a method used to help students gain a conceptual understanding through inductive reasoning, while also learning the process and nature of science. In DeBoer's (1991) summary of research, the results were inconclusive as to whether inquiry methods requiring inductive reasoning were more effective than methods using deductive reasoning.

Scientific Literacy

Another term, with meaning similar to that of conceptual understanding, common to science education from the late 1950s through the 1970s and even into the present is “scientific literacy”. Both prior to, and following, the launch of Sputnik in 1957, the need for development of scientific literacy in all students was deemed necessary. At the very least, American students needed to catch up technologically with other countries. In 1958, Paul DeHart Hurd to described science literacy as an understanding of science and its applications to our social experience. The National Science Teachers Association (NSTA) in 1971 made scientific literacy the major goal of science education. The scientifically literate person was described as one who “uses science concepts, process skills, and values in making everyday decisions as he interacts with other people and with his environment.” He/she “understands the interrelationships between science, technology, and other facets of society, including social and economic development” (National Science Teachers Association, 1971, pp. 47-48, cited in DeBoer, 1991).

In 1992, the NSTA published “The Content Core: A guide for curriculum designers” essentially summarized the education criticisms and proposals since the turn of the century. These advocated for a shift from rote memorization and to allow students to see how science and society relate. In order for this to happen, the NSTA claimed science instruction should sequence material in accordance to students' development, interest and ways of learning. Broad science ideas should be integrated throughout the disciplines for which they are used. Inquiry based instruction with outcome based assessments should be implemented in accordance to students' developmental problem solving capacity (DeBoer, 1991).

Following this publication, the National Science Education Standards (1996) were written with the goal of educating a scientifically literate society. It was believed members of such a society could appreciate the natural world through understanding it, and use this understanding to make informed personal decisions, engage intelligently in debates technological and scientific in nature, and increase economic productivity in an increasingly technological world. The standards provided a framework of what a scientifically literate person should know and be able to do after graduating from high school.

These reports, like many that appeared in the 1980s and 90s, advocate science teaching as one or a combination of the following: teaching science as inquiry, teaching science in a manner that addresses actual, and thereby relevant, problems in students' lives, and teaching science as conceptual change. Each method strives for scientific literacy, bemoans the reliance on a textbook, advocates for hands on learning, and proclaims the need for student-centered learning. Taken together, these ideals form the constructivist philosophy in science education. Constructivism seeks to bring together an image of what science is, derived from sociology, with an image of how learning proceeds, adapted or adopted from the developmental psychologists Jean Piaget and L.S.

Vygotsky. It holds the view that knowledge is actively constructed, and scientific understanding must be built up anew by each individual through the organization and adaptation of experience.

Summary

Nineteenth-century psychology formed the basis for science educators' views of how science is best taught. In these views both perception and conception are important. Sense perceptions link together to form clusters of ideas, and eventually concepts. These ideas are modified by the inclusion of new ones by way of accommodation, or fit into the existing structure through assimilation. In terms of science education, the implications for this idea of concept formation include hands on learning as an essential component of sense impressions. Concept formation is the basis for all understanding; connecting new knowledge with prior knowledge to help organize ideas and make connections, make learning personally and socially relevant. This implies connecting curriculum with prior student experience at a developmentally and socially appropriate level. Learning in science involves reflecting on, discussing, and expanding on the experiences we have had with our physical world. Making linkages between theory and the physical confirmation of theory by means of experimentation within logically organized disciplines enhances the learning of both content and process (DeBoer, 1991).

Within these techniques, there remains substantial variability in how science education in the classroom would appear. However, this foundation does provide educators a place to begin to evaluate the reasons for using a particular approach, and to consider the consequences in terms of students learning, social responsibility, personal satisfaction, and self-regulation.

The following chapter will critically examine contemporary research studies that evaluated many of the instructional techniques alluded to in this chapter. This summary and critique of the literature will include studies of communication, inquiry, motivation, conceptual change, assessment, curriculum, technology, and the nature of science in terms of student learning and conceptual understanding in the classroom. The findings from these studies will inform the classroom implications and suggested direction of future research in chapter four.

CHAPTER 3: CRITICAL REVIEW OF THE RESEARCH

The historical framework provided the basis from which current researchers study conceptual understanding in science. The need for conceptual understanding is well established in the educational community. However, the questions of how such learning occurs and how the schools should encourage students to desire and reach a higher level remain. Researchers are diligently studying students and classroom practices in an attempt to answer these questions.

In reviewing the current research on conceptual understanding in secondary science, studies focused on students' prior knowledge, cognitive conflict, conceptual change, meaningful learning, and instructional techniques for certain learning preferences and goals. Within conceptual change learning, several factors which may promote or impede conceptual change included group collaboration, students' ideas and explanations, students' beliefs about the nature of science (NOS), and motivation. The following chapter critically reviews some of the current literature within these areas.

Prior Knowledge

According to Ausubel's (2000) review of research, students' prior knowledge is the most important information for an educator to be knowledgeable of prior to teaching a topic or concept. He also argued the primary way of adding information to cognitive structure is to link new ideas and details in a subordinate fashion to the anchoring concepts already present. According to Novak (Wandersee et al. 1994), students' prior misconceptions anchor new related learning and often new information causes the misconception to be elaborated or convoluted to accommodate the new information rather than to overwrite it.

Prior knowledge may be elicited through discussion (Asoko, 2002; Bell, 2005; Coll & France, 2005; Geelan et al., 2004; Hammer & Elby, 2003; Pugh, 2002; Swafford & Bryan, 2000; Tao, 2001; vanZee & Minstrell, 1997; Yip, 2004) or in written form (Cavallo, 2003). Several other researchers (Cavalcante & Newton, 1997; Cavallo, 2003; Dalton et al., 1997; McElwee, 1991; Park & Kim, 1998; Vosniadou, 2001) have also examined the connection between students' prior knowledge, and conceptual understanding. Cavalcante and Newton (1997), Cavallo (2003), Dalton et al. (1997), and Park and Kim (1998), analyzed how prior knowledge of students' conceptions affect learning when an inquiry method of instruction is used.

Cavallo (2003) probed Novak's assertion that prior conceptions could be either an asset or liability for meaningful learning. Cavallo wondered if terms associated with anchor concepts could serve as prompts or cues when students' mental models are elicited in written form. Essentially, when using the inquiry method, in this case the learning cycle, should students be given key terms before, or after, initial instruction and investigations?

Cavallo (2003) studied 60 ninth-grade physical science students (26 males, 34 females) in four separate science classes located in a mid-western city of the United States. The ethnic composition of the students was over 85% Caucasian, with the remaining 15% consisting of approximately equal percentages of Asian, Native American, and African American students. The instructor of all four classes was one experienced teacher, who used the same inquiry-based, learning cycle curriculum for all classes. In this study, the learning cycle consists of three phases: exploration, term introduction, and concept application. In this particular school district, the students had experienced this teaching model and curricula throughout their education in this district, so they had similar content backgrounds and were accustomed to the inquiry format.

The goal of this research was to explore the nature of understandings, as well as trends, shifts, and differences that may emerge from students' responses on two open-ended test question formats: one that used key terms, and one that did not use key terms. In doing so, the study examined students' alternative conceptions, misconceptions and other errors about chemical reactions.

Of the four classes, two classes (28 students: 11 males, 17 females) were evaluated using open-ended test questions without key terms and two classes (32 students: 15 males, 17 females) were evaluated using the same open-ended test questions with key terms. Analyses of prior achievement in these classes showed students were generally equivalent in their knowledge of physical science concepts prior to the study. The open-ended questions asked students to summarize everything they know about chemical reactions. The question including key terms asked students to explain how chemical reactions may be related to atoms, compounds, and chemical change.

Qualitative evaluation and categorization of students' statements and propositional knowledge involved consideration of both written answers and illustrations. Students' essays were then scored according the degree of understanding represented in their essay. The interpretative system used in the study to score students' responses was a concept evaluation scheme, developed and used in previous research, which used six categories to score students' essays. The scores on students' essays ranged from a score of 6, representing sound understanding, to a score of 1, representing a non-response. These scores were used in the statistical data analyses portion of this study. The examination of students' explanations of chemical reactions revealed that the students who were not given key terms in their pre-tests had about half the total number of misunderstandings as the students provided with key terms (11 versus 21). However, students not given key terms exhibited a nearly equal number of types of misunderstandings (8 types) as students given key terms (9 types).

The first evaluation after the learning cycle showed little or no change in the total number of misunderstandings or in the number of types of misunderstandings for students given either form of the test. Significant, positive shift in student understanding occurred between the pre-test and post-test 1, and overall, between the pre-test and post-test 2 ($p < 0.01$). There was no significant shift in understanding between post-test 1 and post-test 2. No differences in the shifts in understanding with respect to test form were found.

Students with no key terms gave a more diverse range of initial conceptions of chemical reactions; these explanations were also more qualitative in nature than those elicited by students given key terms. Students with both forms of the essay attained more sound understandings through the learning cycle. This study did not examine the effect of providing key terms prior to instruction on the persistence of misunderstandings. For both forms of the essay question, minimal adjustments were made between the two application phases. After the first test, there were no statistical differences in the extent of student understanding elicited. The only distinctions between the test forms were observed in qualitative and descriptive analyses.

Cavallo (2003) asserted these findings support term introduction after, not prior to, initiation of the learning cycle. This is based on fear of eliciting misunderstandings prior to students having experience with the concept. However, the scale used to measure shift in understanding does not lend itself to the use of mean scores for analysis. The difference between a score of one and three, no answer and incorrect information respectively, is not equivalent to the difference in understanding between a score of four and six, partial understanding with specific misunderstanding or alternative conception and sound information, respectively. In addition, the effect of providing key terms only after initial investigation or instruction was also not examined. Based on Ausubel's assertion that students' prior knowledge is essential information for an educator to have, this fear would be unfounded. On the other hand, if eliciting this information simultaneously forms misconceptions, it could be counter productive.

Cavallo's (2003) study did emphasize the need of educators to consider the purpose and potential of application activities' ability to promote student understanding and to be aware that students construct an understanding of the concept during initial experiences with the concept. Educators must carefully implement instruction to guide students toward what may be the first and only construction of a particular concept.

Cavalcante and Newton (1997) examined three parallel classes of 10 year-olds, each of which used a different permutation of three teaching methods on three topics. These teaching methods included one that provided a conceptual structure (P), one that initially withheld a conceptual structure (W), and one that used a 'combined' approach (C). The lessons that provided a conceptual structure began with a video presentation of the conceptual information relating to each topic. This provided a short introduction relating the content of the lesson to everyday life. For example, in the topic on materials, common objects were used to illustrate the variety of materials available. The presentation continued with an account of the properties of various materials, such as the elastic properties of a bath sponge. It was followed by a demonstration of the behavior of a sponge when subject to a force. The elastic nature of the material was described. The lessons that withheld a conceptual structure gave the children a problem to solve by practical investigation. For materials, the children were set the task of finding out if there was a pattern to the behavior of a sponge when compressed. This provided an opportunity for the pupils to construct the significant relationship themselves. Lessons with a 'combined' approach began with a videotaped presentation followed by the relevant investigation

All classes in Cavalcante and Newton's (1997) study were taught all the topics but in different ways. Class 1 was taught about Materials (W), Soils (P) and Camouflage (C) but Class 2 received Materials (C), Soils (W) and Camouflage (P). Class 3 completed the set with Materials (P), Soils (C), and Camouflage (W). The pre-test was applied more than a month before the presentation of the lessons to reduce the likelihood that they might focus attention on particular information when the lessons were presented. In essence, all versions of the lessons on a given topic offered the same information and were similar in form of those in a previous exploratory study. The P form simulated a lesson beginning with an oral presentation of information followed by some related worksheet. The W form simulated one beginning with a practical investigation followed by a reading task and intended to rehearse the expected conceptual learning. The C form simulated a 'belt and braces', combined approach which some teachers seem to use.

Open-ended questions requiring explanation and application of knowledge were used to test understanding in Cavalcante and Newton's (1997) study. Briefly, the scoring system amounted to: 0: no or irrelevant response or use of given terms without explanation; 1: misconceptions or explanations based on various irrelevant concepts; 2: partially correct conception with misconception; 3: descriptive conception; 4: partial, theoretical conception; and 5: complete theoretical conception. The Pearson correlation between the scores awarded by the raters ranged from 0.83 to 1.00. Each test pupil's total score relating to each lesson was converted to a score out of 10.

The approaches were not equal in their effect on the mean gain in understanding ($p = 0.018$). Generally, Cavalcante and Newton (1997) found the C and P forms produced greater gains than the W form. The lessons tested here were not equal in their effect on conceptual understanding. Conceptual understanding was best served by the lessons that provided a conceptual structure at the outset. A practical investigation followed by a safety net of relevant textual information produced generally lower gains in conceptual understanding than those produced by the other lesson forms. In this instance, the results indicate that this particular kind of investigation lesson generally did not provide the best support for conceptual understanding.

The significant interaction between topic and approach showed that no single approach is always the best for producing gain in conceptual understanding. Cavalcante and Newton (1997) believed this to show a relationship between prior knowledge, and cognitive demand. They hypothesized when a learner has a low level of conceptual knowledge and understanding to start with, then providing a conceptual structure may be particularly beneficial. As the initial level of conceptual knowledge and understanding increases, the value of providing a conceptual structure may decline. In this event, the gap between the gains in the P and W lessons could decrease.

At higher levels of initial conceptual knowledge and understanding, Cavalcante and Newton (1997) found the advantage may move to lessons that withhold conceptual structures. The largest difference between the gains from the P and W lesson was for soils, which also had the lowest level of prior knowledge. The mean pre-test scores for the other two topics suggest that children's starting points were, on average, similar for these topics and higher than for soils. Their P-W gain differences were also similar to one another and less than for soils. This provides some support for the view that the children's initial level of knowledge and understanding determines the size of the gap between the effect of the P and W lessons. However, other factors, such as motivation could also play a role in student performance.

The common problem of using mean scores from Likert scale responses also surfaced in this study. In addition, the sample size was relatively small for the variety of permutations studied. These factors make it difficult to draw specific conclusions about effective teaching practices. The study does support Ausubel's and others' assertion that students' prior knowledge is an important factor to consider when planning instruction.

Park and Kim (1998) compared students responses to experimental evidence obtained through simple observations (N = 20) and those obtained from controlling variables (N = 23) to determine how students' responses to experimental results differ when the evidence results from varying levels of inquiry skills. Participants were randomly assigned to one of the two aforementioned experimental evidence groups from a pool of 120 randomly selected high school science students in Seoul, Korea. It should be noted that to study science in high school, students must have been academically in the top 5% in middle school. Thus it was assumed these students were both scientifically talented and experienced in controlling variables.

The forty-three students in Park and Kim's (1998) study were selected on the basis of misconceptions apparent from the pre-tests. The experimental evidence was fictitious, and intentionally designed to conflict with students' preconceptions. Experimental evidence based on simple observations and the results obtained from them, represented a basic science inquiry skill as defined by Science-a Process Approach. The evidence based on controlling variables represented an integrated science inquiry skill as defined by Science-A-Process Approach. Fictitious written results were used to eliminate the effect of direct observation by the participants.

Student responses from Park and Kim's (1998) study were then analyzed and categorized into either acceptance of the results and changed preconceptions or denial of results and preservation of preconceptions, possibly through slight cognitive modification. Ninety-one percent of the controlling variables group accepted the results, however, only 45% of the simple observation group accepted the results (X^2 (1, N = 23) = 10.874, $p < 0.01$).

Park and Kim (1998) hypothesized the significant difference in student responses could have been attributed to the higher cognitive demand required in analyzing the controlling variables experimental results. Additional factors, which may have influenced students' responses, were also reported. In the simple observation group, the experimental result only contained contradictory evidence, whereas the controlling variables experiment included evidence that both supported students' preconceptions and contradicted them. The researchers also argued first hand observation would not have significantly altered the results because students select, organize and interpret information based on their own prior knowledge or expectations, rather than recording and accepting all information presented to them.

The results of Park and Kim (1998) did support the idea that learners must challenge the information they are presented with and intentionally try to make sense of it. However, the researchers did not examine the permanence of the students' conceptual change and whether the students could apply their knowledge to situations beyond the two multiple-choice questions given.

Dalton et al. (1997) examined the differences in impact on fourth grade students' conceptual learning from a two month supported inquiry science (SIS) unit versus an activity based science (ABS) hands-on electricity unit. This study sought to analyze variance between students with Learning Disabilities (LD), and low (LoA), average (AveA) and high (HiA) achievement students to evaluate how hands on science instruction should be implemented so that all students can benefit from better conceptual understanding.

Dalton et al.'s (1997) study included eight fourth grade classrooms; six were from five schools in an economically diverse community in a northeast metropolitan urban district and the other two classrooms were from a school in an affluent suburban district. The total number of students included in the study was 172 and 33 of them were considered to have LD. All but one teacher had at least nine years of experience and all were interested in improving their science teaching. All of the urban teachers had previously relied primarily on textbooks or weekly visits from their science specialists, whereas the suburban teachers had extensive experience using hands-on science.

The pre-test, a paper and pencil questionnaire of Dalton et al.'s (1997) study, showed students' prior knowledge of electricity didn't differ as a function of LD or achievement. The questionnaire asked students to convey their understanding, in words or illustrations, of simple, series, and parallel circuits and conductors/insulators. The questions included key terms and were open-ended. This questionnaire was used as both the pre-test and post-test. In addition, a constructed diagram test was also used as a post-assessment tool. This test included circuit diagrams where students would decide whether or not a circuit was complete and trace the path or explain why it wouldn't work.

Dalton et al. (1997) found both the ABS and SIS units provided a safe environment for expressing emerging or divergent ideas, and specific guidelines and procedures for collaborative science inquiry. This inquiry included working collaboratively in pairs, manipulation of bulbs, batteries, and wires, completion of data sheets, and participation in class discussions. The SIS curriculum emphasized conceptual change by providing more opportunities to discuss evolving ideas, focusing on a unifying concept, incorporating misconceptions into discussions and further experimentation, sharing predictions and outcomes, and student generated illustrations.

Dalton et al. (1997) found teacher affects were not statistically significant ($p > 0.20$). In addition, variance of student performance by achievement level was not statistically significant for the questionnaire. Students' performance, in terms of gain scores from the questionnaire and diagram, showed a significant advantage for students in the SIS group ($p < .0001$ for both tests). The SIS average 18.05-point gain on the questionnaire was approximately twice that of ABS students. Suburban students had greater gains than urban students on both the questionnaire and diagram test ($p < .0002$ and $p < .0001$, respectively) and students with LD had smaller gains than their peers ($p < .0002$) on the questionnaire. However the diagram test showed students with LD performed comparably to their LoA and AveA peers. It should be noted the diagram score is based on posttest score, not gain score.

Dalton et al. (1997) concluded hands-on science is an important component of effective science instruction for all students, but must be structured in a way that focuses on students' evolving alternative conceptions as the SIS unit did, rather than procedures and outcomes as in the ABS unit. The SIS unit required students to experiment with their own designs and hypotheses and to debate these ideas with their classmates. They believed the SIS principles most likely to influence student learning and conceptual change were both the careful analysis of underlying concepts and analysis of children's misconceptions. The SIS principles also included many opportunities for students to co-construct meaning with their partners and classmates via recursive experience-based discussions, all the while guided by the teacher-coach who was knowledgeable about likely misconceptions.

This was a well-designed study employing a relatively large and diverse population of students. The researchers carefully checked for differences between the teachers and students both between the schools and ability levels. Their analysis of the data was clear and deliberate. An important aspect not studied is the permanence of students' conceptual understanding. This research supports Ausubel's assertion that the most important information for a teacher to have is the prior knowledge of the students as well as an understanding of the underlying concepts.

Conceptual Change and Cognitive Conflict

Dalton et al (1997), Vosniadou (2001), and McElwee (1991) studied the interaction between students' prior knowledge and the propensity of conceptual change learning in a constructivist learning environment. Once students prior knowledge, conceptions, and misconceptions are established, cognitive conflict (Chi et al., 1994; Jonassen et al., 2005; Niaz, 2002; Park & Han, 2002) has been used to guide students to scientific understandings. McElwee (1991) and Vosniadou (2001) intentionally incorporated information about students' prior conceptions to initiate cognitive conflict and promote conceptual change.

McElwee (1991) explored the personal ideas held by a group of American grade 8 pupils (both sexes) on the boiling of water to examine the changes that take place in conceptual knowledge immediately after instruction using a strategy of conceptual conflict resolved through the mediation of analogy. The pupils were divided into two classes, one of high academic ability (N = 21), and the other of average ability (N = 16). A group of ten pupils was randomly selected from the average ability class for an in-depth interview concerning their ideas. Each pupil had been assessed using the California Achievement Test (CAT). They were assessed for formal reasoning using a pencil and paper test, which required pupils to justify their solutions to problems using a multiple choice format. This test correlated well (0.80) with a clinical interview method. Identification of personal concepts was used to determine whether these concepts resisted change or were integrated into a scientific explanation as a result of formal instruction involving conceptual conflict and using analogy as a mediator between old and new knowledge.

McElwee (1991) found conceptual changes were assessed immediately subsequent to instruction. In this study three different formats were used to elicit students' thoughts about what was happening during demonstration experiments. These included:

1) an unstructured format where students described their thoughts on paper in their own words 2) a structured multiple choice format, containing alternative concepts previously identified in a pilot study and 3) 10 from the average ability group pupils were then interviewed in depth concerning the demonstration. Each audio taped interview session of 20 minutes was transcribed and analyzed. The interviews were used to give validity to misconceptions identified in the pencil and paper tests and to isolate further misconceptions not previously exposed.

In McElwee's (1991) study, first, students were allowed to observe a demonstration of water being heated over a Bunsen burner in a beaker. In this demonstration the teacher directed the observation. A follow-up demonstration on boiling was carried out to determine if personal constructions, used to explain the boiling of water, would also be used to explain boiling at a lower temperature under reduced pressure. Consequently the beaker of water was cooled and placed in a sealed plastic container attached to an electric vacuum pump. Immediately after the demonstration, pupils were questioned to ascertain whether they had existing personal concepts to explain a phenomenon with which they were familiar in the context of home experiences.

Based on the students' misconceptions, McElwee (1991) designed an instructional program that included intentional construction of conceptual conflict. Concepts exposed by the previous tests were addressed and challenged while the experiments were demonstrated again. Then the formal explanation of boiling was presented verbally with support of the blackboard in a traditional manner, but the presenter took into consideration the pupils' present understanding. The aim of this method was to make the explanation more meaningful to the pupils in the sense used by Ausubel (2000) and described by him as meaningful verbal learning. The explanation of boiling involved a description of molecular movement on heating, using an analogy of a beehive and the effects of heating the hive.

McElwee's (1991) results showed some pupils acquired a scientific understanding of the process of boiling but for others personal misconceptions continue to be held. Those who scored highest on the CAT showed the greatest ability to integrate scientific concepts and personal concepts. There would appear to be a link between previous achievement in science (CAT score) and the ability to change personal concepts. Using Spearman's rank order correlation coefficient between CAT scores and number of correct answers to test questions produces a value of 0.84. Formation of incorrect concepts may be the result of applying an idea, learned previously in science class, in an inappropriate way to explain a new phenomenon. Of the 10 case studies, only three pupils could be said to have adopted and integrated a new cognitive structure although larger percentages did integrate specific concepts. The researchers argued this might indicate that for some students the analogy was sufficient to aid their transition from personal to scientific understanding. Some pupils can therefore benefit from the teaching approach used in this study. However, the remainder did not adequately benefit and either compartmentalized their new knowledge or failed to change their personal concepts to scientific concepts.

The analogy used in this study, in my opinion, was not sufficient to explain molecular movement under low pressure. This is a difficult concept for students, which incorporates many chemistry concepts. It was not surprising the results obtained through the use of a beehive analogy showed little conceptual change. This analogy would have not been sufficient to explain the properties of a gas under low pressure. This study does highlight the need for teachers to be selective with the analogies they use in order to help students mold their personal understandings into scientific ones without reinforcing common misconceptions.

Vosniadou et al. (2001) incorporated research on the acquisition of science concepts into the construction of an experimental learning environment. The researchers distinguished their view of science learning from that of the empiricist view in terms of conceptual change. The researchers were interested in “learning as a process that requires the significant reorganization of existing knowledge structures and not just their enrichment” (p.383). Specifically, the researchers wanted to determine whether the students had developed an explanatory framework that incorporated multiple concepts.

Vosniadou et al.'s (2001) experimental learning environment included students working in small groups, beginning class with a question—individually answered in a notebook, followed by a small group discussion in which agreement on a response was to be reached for presentation to the class and general discussion. Inevitably disagreements between the groups arose. In-class experiments using everyday materials were used to provide an objective answer. In addition to these activities, the researchers also took into consideration a number of other factors concerning student acquisition of the concept of force. These considerations included students’ prior knowledge of the concept of force that were based on the results of previous research and analysis of the pre-test responses from the experimental group. Researchers also considered the use of models, symbolic representations, measurements, and cognitive conflict, carefully ordered concept introduction, and distinction between the scientific and common meanings of terms.

Participants in Vosniadou et al.'s (2001) study included students from two separate classes in a school in Athens Greece. The experimental group (N = 24) received instruction previously described and the control group (N = 17) received the regular instruction as specified in the National Curriculum, by the regular teacher. Pre and post-tests were identical and given to both the experimental and control groups. In-depth interviews were used to clarify students' understanding and corroborate analysis of the written tests. The researchers found statistically significant differences in cognitive gains between the experimental and control groups.

Vosniadou et al. (2001) attributed these differences to questioning methods resulting in complex student explanations, which allow student beliefs and conceptions to be negotiated among the class members. The authors argue it is this meaning negotiation process that “fosters the deeper understanding required for conceptual change”. The environment appeared to be a fertile ground for cognitive conflict, but also nurtured resolution of this conflict.

This study successfully incorporated several changes based on research into the learning environment to promote conceptual change. However, the research does not determine whether one particular change, such as incorporating students' prior knowledge, or a combination of changes contributed to the gains in the experimental group. The study also did not explicitly state whether the instructional time in each group was equivalent. The findings from this study support the need for teachers to create learning environments with a variety of instructional strategies and where students feel safe to negotiate their current beliefs with new information.

Conceptual Change and Group Collaboration

In addition to Dalton et al (1997), Vosniadou (2001), and McElwee (1991), numerous others have also studied conceptual change learning in relation to specific instructional strategies. Niaz (2002) studied how generating situations and experiences in which students were forced to grapple with and reconcile alternative responses in a group setting so all students may benefit from the cognitive conflict of others. Tao and Gunstone (1999) also incorporated a collaborative learning strategy to elicit cognitive conflict and promote conceptual change. Basili and Sanford (1991) included small group cooperative tasks to elicit misconceptions, which could then be discussed in contrast to the scientific conceptions that had been taught through direct instruction. Nakhleh (1996) incorporated groups of six-nine students who worked on common problems and then presented the proposed solutions to the other groups. Tao (2001) facilitated students confronting varying views while working in small groups to solve qualitative physics problems. De Vries et al. (2002) studied how the design of a computer mediated CONNECT program facilitated co-construction of knowledge.

Niaz (2002) studied two sections of freshman chemistry classes at a major university in Latin America to inform the construction of a teaching strategy that could facilitate conceptual change in students' understanding of electrochemistry. During the first three weeks of the semester, both the control group (n=35) and the experimental group (n=33) were presented the topic of electrochemistry in the same manner, by the same teacher (Niaz). Students' assignment to a section was not based on any particular variable related to their academic/cognitive ability. In order to compare the performance, both groups were tested (pre-tests 1, 2 and 3) on a monthly exam during the fourth week.

The class in Niaz's (2002) study was not audio taped because the pilot study showed audio taping inhibited students' participation. Instead, students’ comments were reproduced from the authors’ notes taken during class. Besides the two problems included in the two teaching experiments, both the experimental and control groups solved the same set of 12 other problems of electrochemistry during the first three weeks of the semester. In order to compensate for the two teaching experiments, the control group solved two similar problems with a traditional format. Both the experimental and control groups used an interactive participatory approach to solving the problems. In both groups, the teacher encouraged students to discuss strategies and often called students to the chalkboard to solve problems. Except for the activities realized in the sixth and seventh weeks, every effort was made to provide similar experiences to the two groups. It is important to note that control group students also, at times, produce conflicts based on alternative responses. These conflicts are, however, produced randomly and it is difficult to pursue them without the ‘teaching experiments’.

Niaz (2002) found the performances of the experimental and control groups on the three pre-tests were very similar, and the differences are statistically not significant. For the experimental group the performance dropped to 30% and the control group to 34%. Niaz (2002) explained this drop by suggesting that pre-test 3 requires some degree of conceptual understanding. Students had difficulty with pre-test 3, despite having solved at least four similar problems in class. However, no particular effort was made to highlight the conceptual framework of such problems. Niaz investigated the conceptual difficulty faced by students on pre-test 3 and found students who could not correctly answer this question lacked the conceptual understanding required. These findings were the basis for the design of the teaching experiments.

The major objective of Niaz's (2002) teaching experiments was to generate situations/experiences in which students were forced to grapple with alternative responses leading to cognitive conflicts/contradictions. Teaching experiments were based on the premise that providing students with the correct response along with alternative responses creates a conflicting situation that is conducive towards an equilibration of their cognitive structure/repertoire. Design of the teaching experiments facilitated not only teacher-student interaction but also student-student interaction and small group interaction. Because the students followed the same sequence of steps, it was possible for the teachers to intervene whenever they felt the need to do so.

After Niaz's (2002) experimental treatment (teaching experiments), performance of the experimental group improved significantly (55%), ($p < 0.05$) as compared to the control group, on post-test 1. Then performance decreased once again to 36% on post-test 2. The decrease was attributed to the slight increase in complexity of the problem. The experimental group did perform significantly better than the control group ($p < 0.01$) on post-test 2. The difference in performance on pre-test 3 and post-test 1 was not significant for the control group. Niaz (2002) believed these results indicated students' conceptual understanding of electrochemistry had gone beyond that of routine plug and chug problems such as pre-test 1 and 2 due to the 'teaching experiments' which led students to cognitive conflicts. Niaz also stated that without the teaching experiments, incorrect responses only served as isolated, individual cognitive conflicts, rather than a conflict and possible resolution all students could experience and benefit from.

Niaz (2002) admitted that teaching experiment 2 tried precisely to familiarize students with the conceptual framework required to solve post-test 2, and claimed these results indicated that students require considerable experience and explicit instruction with such conceptual problems. In addition, the results show that a small increase in the complexity of the required conceptual understanding in order to solve the problem, or an increase in the complexity of the problem can present students with considerable difficulty. Thus, teaching experiments must be designed for particular aspects of a problem situation in order to facilitate conceptual change.

Considering the presence of only one experimental group and one control group each with $N < 40$, generalizations from these findings would be tentative. In addition, the researcher was also the teacher and had a vested interest in the outcome of the research. Even if the teaching experiments could be considered “successful” solely on the basis of fostering conceptual change better than the control group, an important finding was the teaching experiments need to be tailored to the specifics of a problem situation in order to facilitate conceptual change. All things considered, specific generalizations should not be gleaned from this study.

Tao and Gunstone (1999) asserted collaborative learning provided students with experiences of co-constructions of shared knowledge and understanding. Collaborative learning experiences also provided students with peer conflicts, gave peer support and helped students get through the tasks. Even though these learning experiences provided a high joint on-task engagement that was high in equality and mutuality, this did not necessarily mean cognitive engagement. It appeared that students also needed to reflect on and reconstruct their conceptions. Peer conflicts did not always produce conceptual change. They appeared to work only for students who were prepared to reflect on and reconstruct their conceptions. Developing shared knowledge and understanding was important, but to achieve conceptual change, this needed to be accompanied by students' personal construction and sense making of the new understanding. Both personal and social construction of knowledge appeared to be significant in the type of context provided in this research.

Tao and Gunstone's (1999) study revealed of the 14 students, six showed substantial conceptual change (one of whom achieved no conceptual change at the post-test but showed substantial change at the final interview), one showed some change, and seven showed no change at the post- or delayed post-test. Of the five students who achieved substantial conceptual change at the post-test, two showed further improvement in the delayed posttest, one sustained his change, one showed deterioration, and one student was absent.

Tao and Gunstone (1999) noticed students experienced conflict when they disagreed on the prediction/explanation. For most of the tasks, students co-constructed shared understanding and agreed on the predictions, but there were also instances of peer conflicts. Some of the conflicts were resolved with one student eventually agreeing with the other, i.e. they reached shared understanding as in a co-construction. The number of peer conflicts ranged considerably, to some extent, this depended on the contrasting conceptions held by students in the dyad prior to instruction.

Most of the tasks in Tao and Gunstone's (1999) study were carried out by the dyads as co-constructions in which students completed and built on each other's ideas and incrementally developed shared understanding. Peer conflicts occurred in tasks in which students disagreed on the prediction and this required them to justify and defend their positions. Although the research did not use a treatment–control-group design, from the rich qualitative data, there appeared to be strong support for the idea that students would not have been able to carry out the tasks as successfully as they did, if they had worked on the tasks alone. Collaborative learning provided peer support and helped students get through the tasks. However, this might or might not have resulted in conceptual change. This appeared to depend on whether the students were willing to cognitively commit themselves to the tasks.

Tao and Gunstone (1999) found engagements of high equality and mutuality were a means to getting students to reflect on their conceptions. Collaborative learning with high joint on-task engagement, which was high in equality and mutuality, helped foster conceptual change, but did not necessarily ensure change. To achieve conceptual change, it appeared that students needed to reflect on and reconstruct their conceptions. Peer conflicts appeared to have impact on some students but not on others, and some students achieved conceptual change without experiencing any peer conflicts at all. It appeared that the crucial factor was whether students were prepared to reflect on and reconstruct their conceptions.

The Force and Motion Microworld (FMM) programs in Tao and Gunstone's (1999) study provided students with many opportunities for co-construction of shared knowledge. During the process, students complemented and built on each other' s ideas and incrementally reached shared understanding. Students' conversational interactions showed unequivocally that this led to conceptual change during the FMM lessons. However, not all students sustained their conceptual change after instruction.

One possible explanation for this is that, in addition to construction of shared understanding, the students who sustained their conceptual change also underwent personal construction of the new understanding. The peer interactions helped students get through the tasks and develop shared understanding, but students needed to make sense of the new knowledge before they could internalize it. They needed not just to complete the task but also to reflect on their conceptions and decide whether or not to change them in the light of the shared understanding. Those students who reverted to their alternative conceptions shortly after the FMM lessons apparently did not internalize their new, shared understanding. They appeared to be satisfied with the completion of the tasks and not to have given much thought to the new understanding. This research gives support to the claim that both social and personal constructions of knowledge are important for conceptual change.

This research shows that social construction of knowledge took place during peer collaboration and in many cases this led to students' conceptual change in the context of the tasks attended to. However, Tao and Gunstone (1999) found when probed at a later time, many students had regressed to alternative conceptions. It is suggested that in the co-construction of shared knowledge, students needed also to personally make sense of the new understanding. When the co-construction of knowledge was accompanied by personal construction, conceptual change became stable over time. When students did not personally make sense of the new understanding, their conceptual change was short-lived. Some support for this assertion can be found in other recent studies. Many students developed shared knowledge with their partners in the collaborative tasks, but they failed to personally make sense of the new understanding. Consequently, these students could not sustain their conceptual change after instruction.

This research had not been designed specifically to investigate students' metacognitive skills, but there was some indirect evidence from the data. At the final interview, several students who achieved substantial conceptual change indicated that they were aware of their alternative conceptions and could clearly state the conceptual change they had undergone. Tao and Gunstone (1999) also claimed that they constantly tried to understand and make sense of what they learned.

This small, qualitative study may have revealed more about motivation and metacognition than collaborative learning in producing lasting conceptual change in students' understanding. Students who took initiative to intentionally reconstruct their knowledge showed the most lasting change. In general, this study illuminated the need for research into motivation and conceptual change. This connection was later supported in literature reviews by Andre and Windschitl (2003), diSessa et al. (2003), Hynd (2003), Linnenbrink and Pintrich (2003), Mason (2003), and Southerland and Sinatra (2003).

Basili and Sanford (1991) examined the effect on a treatment group of students who participated in small cooperative group tasks aimed at eliciting misconceptions to be discussed in contrast to the scientific conceptions that had been taught through direct instruction. Participants included 62 students from a suburban community college, enrolled in a two-credit non-laboratory course as preparation for general chemistry, 35 of which were chosen to receive the treatment condition. The study did not specify how these students were chosen. However, the treatment and control groups were in separate sections of the same course.

Both the treatment and control groups in Basili and Sanford's (1991) study were given the same pretest, in which no significant differences between the groups were found. In addition, the treatment group received instruction in the making of concept maps, and was informed of the nature and requirements of the group sessions. These sessions took place one class period per week, where students worked in groups of three to five chosen by the instructor, to provide intragroup homogeneity in terms of age, sex, and gender. During the following period a test was administered. An incentive of bonus points was offered to groups if all group members received a score of 70 or better on the exam. The control group also was given a test. However, bonus points were offered for submitting a practice exam on the day of the test and only indirectly related to test performance. Rather than working in small groups, the control group received a demonstration related to the course work, but not specifically addressing the target concepts.

Basili and Sanford (1991) used chi-square analysis to compare post test results of the treatment and control groups. They found the treatment groups to have a significantly lower proportion of misconceptions ($p < 0.05$). In addition the researchers encoded group discussions to see how verbal behavior was related to conceptual change. They found the students who made no conceptual change as indicated by the posttest, also had a higher frequency of verbal behavior associated with impeding conceptual change.

These findings, however are suspect due to the ambiguity of how the treatment students were chosen, and the incentives to perform well on the exam that were not provided to the control group. In addition, it could be argued that the demonstrations provided actually decreased the amount of pertinent instruction the control group received, since the demonstrations were not associated with the target concepts the students were tested on. Also, the coding system used to evaluate both verbal behavior and group dynamics was highly inferential and not supported by any other evidence.

This study had several flaws and the findings may only be of value if they are corroborated by other, more careful, studies.

Nakhleh et al. (1996) were interested in increasing conceptual understanding in relation to algorithmic understanding in chemical concepts. They employed an action research method in studying the effect of curriculum and instruction innovations on students’ conceptual understandings and their attitudes towards the innovations. Data on the participants' attitudes towards these innovations were collected from initial and final surveys of students in the course ($N = 55$), from interviews with selected students, as well as interviews with the professor and the two teaching assistants. Analysis of the students' groupwork reports for each special session-- one former lecture period dedicated to conceptual problem solving, and exams were used to measure student understanding.

Nakhleh et al. (1996) found students' conceptual problem solving ability increased between exam one and two ($N = 44$). On the first exam, there was a significant ($p < 0.05$), 21%, difference between students performance on solving algorithmic over conceptual questions. On exam two, the difference in problem solving ability was not statistically significant ($p < 0.05$), and thus becoming more skillful at solving problems requiring conceptual reasoning and understanding. However, between exam two and three, the special sessions were less frequent, due to professional commitments of the faculty and researchers, and the differences between the students' ability to solve algorithmic problems over conceptual ones was again significant ($p < 0.05$). Prior to the final exam, the special sessions were reinstated and the differences again shrank to a non-significant level ($p < 0.05$).

Nakhleh et al.'s (1996) results reinforce the theory that a concerted effort must be made to help students reach a conceptual understanding. In this case, groups of six to nine students worked on a common problem for about half of one period, with resources such as text, notes, the professor, the authors, and the two teaching assistants. The second half of the period was devoted to student presentations. The special sessions allowed for more interactions, both between the students and between the professor and the students. The professor found opportunities to share current research findings from a recent conference, which increased student interest in the kinetics section of the course. The sessions also helped the professor to get an idea of student misunderstandings and weaknesses. The professor was also enthusiastic about the changes and noted students seemed more alert and active in the course than in previous years, and considered this to be his best teaching experience yet. However, both the students and professor were apprehensive at first and needed the constant support and guidance of the researchers to make the innovations a successful experience.

Simply having so many professional assistants at the students' disposal could have been a major factor in students' success. The research does not tease out the difference between improved conceptual understanding due to a smaller student-professional assistant ratio and the type of learning experience. But as Tao (2001) suggests, “Simply interacting with content knowledge is not usually sufficient to become convincing enough to overcome student’s intuition. Co-construction of knowledge through collaboration with peers is also needed in order to overcome intuition”.

Tao’s (2001) study included providing varying views to eighteen 12th-year students as they solved qualitative physics problems using a collaborative effort. The students worked in dyads on three problems in which they had to consider and confront each other's ideas, consider multiple solutions to a problem, and compare these solutions with their own. The study used the theory that the varying views would bring students to discern the different critical aspects of the problem at hand and this would aid the development of conceptual understanding. The results show that confronting students with varying views have positive effects on students’ learning from pre- to post-test at 0.05 levels. In this statistical test, the scores of each dyad at the pre-test are compared with the mean scores of the two students in the dyad at the post-test. Considering the level of difficulty of the problems (as shown in students’ performance in the pre-test) and the fact that there was a time span of three and half months between the feedback and the post-test, the students’ improvement in performance at the post-test was substantial. Audio recordings were compared with field notes; pre and posttests were evaluated and found to parallel in concept tested and difficulty. The students chosen were from Hong Kong schools where only one third of the students from year 11 are offered the opportunity to participate in this year 12 program. Therefore they are exceptionally motivated. If motivation is a factor in conceptual change learning as Pintrich et al. (1993) and Tao & Gunstone (1999) suggest, this must be taken into account.

De Vries et al. (2002) examined several aspects of the “CONNECT” program, a carefully engineered, integrated environment and task sequence program. The CONNECT program is designed to promote collaborative confrontation, negotiation, and construction of text environment. It favors the occurrence of epistemic dialog, and creates opportunities for conceptual understanding. De Vries et al. examined why these opportunities might be missed, and the conditions required for students to exploit them.

The 14 volunteer participants of de Vries et al.'s (2002) study were students of one class at the high school level who had not yet had a course on sound as part of their normal curriculum (11th grade, age 16 to 17 years). The procedure consisted of one group session in the classroom, and for each dyad, an individual session in the laboratory. The aim of the group session was to collect students' individual texts. Students were shown the sound video and they individually wrote an interpretation of the two-tambourine CONNECT situation. They also wrote a small text on the topic of censorship on television, which served as a practice text for the CONNECT environment. The individual texts (two-tambourine situation) were analyzed in order to constitute seven dyads. Six of the seven dyads worked with CONNECT and one dyad was used for a side-by-side pilot session.

De Vries et al. (2002) invited the dyads to come to the laboratory at different times. The two students of a dyad were seated in front of a computer in two different rooms in the laboratory. Each session started with a practice period using CONNECT on the censorship texts. The individual texts dealing with the two-tambourine situation were slightly adapted and then displayed on the CONNECT interface showing the author's first name. The students then marked their opinions and discussed their individual texts (Phase 1) and produced a common text (Phase 2). All dialog interventions and task actions (dialog, text typed, and buttons clicked) were written to log files. The dialogs were analyzed to determine the amount and the type of epistemic dialog as a function of the differences in individual texts and opinion marks of the two students of each dyad. The texts were checked for evidence of different underlying mental models.

De Vries et al.'s (2002) qualitative analysis showed episodes in which the occurrence of epistemic dialog was closely related to levels of description, different perspectives and double meanings in the domain, and as such may contribute to the development of conceptual understanding in that domain. The construction of the dyads, aimed at maximizing opportunities for differing viewpoints, conceptions, and models, was not alone sufficient to create cognitive conflict. Several explanations as to why epistemic dialog and conceptual understanding may conflict were presented. De Vries et al. (2002) believed concepts needed to be within the students' capabilities and the concepts needed to be constructed or elaborated during the task sequence. This combination requires students to be sure enough of an idea under construction to defend it, which may cause cognitive conflict that could lead to interpersonal social conflict. This careful balance, as well as the nature of explanation and argumentation, must be learned.

The CONNECT program in de Vries et al.'s (2002) study aimed to mediate conflict and increase conceptual understanding through epistemic dialog. Analysis of students' use of the program found interaction showed a prevalence of dialog over task actions, the type of dialog showed high percentages of explanation and argumentation compared to percentages found in previous research. Although an initially recognized conflict may lead to epistemic dialog, it may not reveal progress towards conceptual understanding. This qualified as a missed opportunity. Instead of students both exploring the differences between their models, one student presented successive explanations of her own model seemingly with a goal of coinciding with the other student’s model. Another route towards conceptual understanding, present in the CONNECT data, was the recognition of a *lack* of understanding. In fact, it is not necessarily obvious that students realize just what it is they do not understand or that they realize that it is the appropriate moment to consult an outside source. The authors argued the arrival at such an impasse could be considered to be a positive outcome in the sense that the students have taken charge of their own pursuit of understanding. The authors believed students may not have been prepared to explicitly disagree, and preferred to ask for further explanation. Discussion was further enhanced when students were asked to write a common text.

The sample size of this study was not sufficiently large to draw generalizations. However the study does reinforce the need for students to be motivated in order for them to examine and construct understandings. The results also indicate technological intervention help mediate social pressures, which may have an affect on students' ability to collaboratively and constructively confront opposing ideas in peer groups.

Conceptual Change and Students' Ideas and Explanations

Fellows (1994) asked students to explain their ideas both orally and in writing to increase their metacognitive awareness and compare their ideas with other students' ideas. VanZee and Minstrell (1997) used ethnographic methods with a case study to qualitatively analyze how teacher questioning, in the form of the “reflective toss”, can assist students by helping them “to make their meanings clear, to consider points of view in a neutral manner, and to monitor the discussion and their own thinking.” Edens and Potter (2003) examined the use of drawings as an instructional tool to promote conceptual change. Park and Han (2002) believed deductive reasoning might be required for students to experience conceptual change.

Fellows (1994) found support for eliciting conceptual change in students through asking students to explain their new ideas both orally and in writing. The teacher in Fellows' study used strategies such as contrasting student's real world conceptions with scientific principles to encourage students to state and clarify their own ideas and elicit alternative conceptions. Fellows followed the conceptual changes shown in 25 students' writing over a 12-week science unit by constructing and comparing concept maps made from their writing as well as from analyzing interviews from six target students before and after the science unit. The six target students were chosen to represent the most diverse range of students in terms of achievement, ethnicity and gender.

Fellows (1994) study found students demonstrated conceptual change by adding new principles to their existing schema and/or reorganizing their schema to better align with scientific explanations. The research also found more than half of the students attained the intended goal concepts when the lesson offered students more focused and balanced opportunities to practice expressing their ideas in written and oral form. Less than half of the students attained the intended goal concepts when these instructional practices were not in place. This supports the need for teachers to offer students opportunities to try out, express, and externalize new ideas to promote conceptual change in science learning.

The major findings from Fellows' (1994) study were based on observations of how students' understanding developed over time rather than simply performance gains. These careful observations accompanied with teaching practices aimed at helping students negotiate their understandings with the intended instructional goals proved to be effective. The students were carefully selected to enhance the diversity of the studied students. In addition, several forms of data were used to understand the development of these students' conceptual understandings. The researchers claim that students' expression of their ideas in written and oral form enhanced learning was supported by their careful research. However, this was accompanied by careful observations and instructional strategies based on these observations. The latter is likely required for the former to be effective.

VanZee and Minstrell (1997) used ethnographic methods with a case study to qualitatively analyze how teacher questioning, in the form of the "reflective toss," can assist students by helping them "to make their meanings clear, to consider points of view in a neutral manner, and to monitor the discussion and their own thinking." The reflective toss refers to teacher utterances that elicit further student thinking about a topic. These come in the form of student statement, teacher question (reflective toss), and then student elaboration. This is in contrast to a common pattern of teacher questioning in which the teacher asks a question, the student responds, and then the teacher evaluates the response. The reflective toss accomplishes many of these goals by putting more emphasis on the students' ideas, engagement in meaningful discussions, and creation of a culture of respect for student ideas. The students' statements before and after the reflective toss were examined to follow the influence of the teacher's questioning on student thinking.

The setting of vanZee and Minstrell's (1997) ethnographic case study was a physics classroom in a suburban setting, with a teacher (Minstrell) who reflected extensively on his own practice, especially questioning techniques. Many of these students went to college and elected to take physics in their junior and senior years. Two thirds of the 31 participants were female. One class discussion, from the fourth day of class, was audiotaped. In addition debriefing sessions, discussions between the teacher and researcher were used to clarify and corroborate the transcribed class discussion.

Evaluation of the transcripts showed Minstrell successfully completed the desired goals and related subgoals mentioned earlier as well as many emergent goals within the eight-minute transcribed portion of the class discussion. If such lofty goals can be accomplished in such a short period of time, in the beginning of the school year, one can only imagine the effect of such instruction on student learning at the end of the school year. This study is part of a larger study, which may reveal more about the lasting effects of several questioning methods. It would be shortsighted to make generalizations from this small study alone.

Edens and Potter (2003) studied the use of descriptive drawings as a conceptual change strategy on the topic of conservation of energy in elementary science. The study participants included fourth and fifth grade students (n=184) in an elementary school in the southeastern United States. Students were randomly given one of three assignments: (a) write about roller coasters using the principles; (b) copy the provided illustration of a roller coaster explaining the principles; and (c) generate a drawing of roller coasters demonstrating the principles, based on their understanding of the explanatory narrative, in a science log. The concepts were related to the law of conservation of energy and included the principles of gravity, friction, potential energy, and kinetic energy. In each case the explanatory text was both heard and read. In addition, students watched a video clip related to roller coasters and read a narrative explaining the law of conservation of energy.

Students completing the generative drawing in Edens and Potter's (2003) study were scaffolded through the process with prompts to pause and create and label a drawing of what they just read, as well as answer questions from their drawing at the end of the passage. All students took both a pre-test and two post tests to measure prior knowledge and factual and conceptual understanding respectively. The second post test was administered two weeks after the study session ended to measure delayed factual recall and conceptual understanding. Both posttests were the same and consisted of questions that were reordered and slightly modified from the posttest. The pretest found no statistically significant differences among the three groups nor between the fourth and fifth graders.

Edens and Potter (2003) found understanding improved for all conditions from pre-test to post test ($p < .001$) and from the posttest to delay test ($p < .001$). Edens & Potter also found a significant number of students ($p < .01$) in the learner generated drawing condition, over the other conditions, modified their beliefs about attributes that make roller coasters coast which included scientific principles.

With these findings, Edens and Potter (2003) concluded pictorial representation provides a viable way for students to learn scientific concepts by helping them to construct mental models on which the learner can make inferences. However, the authors did not examine the possibility of increased student understanding from the scaffolding provided from the drawing prompts and questions, or the framework provided by giving students an illustration to copy. This assistance could also have been provided for the writing group in the form of prompts and questions or summary of the text. In addition, the ability of students to communicate their understanding through writing alone should also have been controlled for. This was a relatively brief study lasting only two 50 minute periods. The authors did not advocate for illustrations to take over current methods but to support student learning through their incorporation.

Park and Han (2002) selected 49 middle school students chosen randomly from a typical eighth-grade class in Kwangju to study the use of deductive reasoning as a method to promote students' conceptions about force and motion. The research explored factors that prevent students from employing deductive reasoning and how those factors can be removed to help deductive reasoning to be activated in students' minds, and, as a result, promote conceptual change through deduction. The first purpose of this study was to find out factors that prevent the spontaneous use of deductive reasoning in conceptual change, and the second purpose was to explore what helps students use deduction to undergo conceptual change. Therefore, this study was carried out in two stages: a preliminary stage and the main one. In the preliminary stage, open-ended and non-structured interviews with middle school students were utilized to determine the preventing factors. In the main stage, through structured-interviews, the researchers investigated the process by which students arrived at their conclusions when they prompted the students to use deductive reasoning.

In Park and Han's (2002) study, the preliminary interview included one randomly selected classroom of grade 7 students (average age, 13 years) from a randomly selected middle school located in Kwangju, one of the five largest cities in Korea. Using the *modus ponens* of syllogism, eight students who turned out to be basic deductive thinkers were selected. These students participated in this interview voluntarily with the aid of a science teacher in that school. Based on results of the preliminary interview, it was inferred that four factors might prevent the students' spontaneous use of deductive reasoning, despite their basic ability of syllogistic reasoning. The results from the preliminary interview were used as the basis for designing the main interview, and for developing instructional aids for removing preventing factors, therefore promoting students' deductive thinking.

Two instruments were used in Park and Han's (2002) study. One was for identifying students' preconceptions about the direction of force acting on the object thrown vertically upward. Another instrument was used to confirm students' basic syllogistic reasoning ability. In this test, there were four types of syllogistic questions involving *modus ponens* (If A then B, This is A), denial of the antecedent (If A then B, This is not A), affirmation of the consequent (If A then B, This is B), and *modus tollens* (If A then B, This is not B). These four syllogistic questions were composed only of symbols, such as 'A' and 'B' without any content. Among four questions, only the first one was needed to draw a valid conclusion in the Deductive Explanation Task (DET). The students who correctly answered the first question, namely, *modus ponens*, were selected and interviewed to further explore the process of drawing conclusions. The main interview sought to confirm students' ability at the basic deductive reasoning by investigating whether or not they used deduction when drawing their conclusion in the DET.

Subjects of Park and Han's (2002) study were 49 middle school students whose average age were 14. They were selected from a randomly chosen eighth-grade class in a typical school in Kwangju. After administering the two instruments, 27 students were selected for the main interview, those who had misconceptions about force and motion in the first instrument and who *also* answered the first question correctly in the second instrument.

Of the 27 students in Park and Han's (2002) study, four major factors preventing the use of deductive reasoning surfaced (P1, P2, P3, and P4). P1: They don't read the premises carefully or drew conclusion based on their own preconception rather than based on the given premises. P2: They can't understand the meaning of the two premises. P3: They can't relate the deductive explanation task with the syllogism; therefore, they can't recognize which part of the premises corresponds to the antecedent or the consequent of the syllogism. P4: They reject the logical conclusion even though they obtain the logically correct conclusion. Seven students (26%) had the first type of preventing factor, eight students (30%) had the second factor, and nine students (33%) had the third factor. At first glance, it appears that the effects of the three types of preventing factors were almost identical. However, it was interesting to note that the second preventing factor, being present in path 5, 6 and 7 (of twelve possible paths, only seven were used) of the process, always existed in combination with others. This indicates that if students could not understand what the premises meant, they were more apt to read the premises carelessly or to experience difficulty in finding out the syllogistic structure of the given DET. According to the deductive normative model of scientific explanation, two premises of deduction consist of the statement about the general law and the statement describing a particular state of event to be explained. Therefore, Park & Han (2002) argued students should first understand the basic law about the relationship between the force and change of motion, and should understand whether or not the moving object changes the speed and/or the direction of motion.

Park and Han (2002) suggested DET can be used in classroom teaching for changing concepts about force and motion, especially for finding out the direction of force on a moving object if the following four premises are used. (1) If the speed of an object is increasing in a straight line, then the net force acting on that object is the same with the direction of its motion. (2) If the speed of an object is decreasing in a straight line, then the net force acting on that object is opposite to the direction of its motion. (3) If an object is at the turning point and about to move backwards, then the net force acting on that object is backward direction at the turning point. (4) If an object moving at constant speed is changing direction uniformly, then the net force acting on that object is perpendicular to the direction of its motion.

This study is limited to the concept of force and motion, especially the direction of force acting on an object that is thrown vertically upward. However, even though this study was carried out using only one concept, Park and Han (2002) believed it can be easily and widely applied for finding out the direction of force acting on object in various motions, including simple pendulum motion, circular motion, projectile motion under the uniform gravitation, and also arbitrary motions. The reason that this application is possible, they argued, is because a DET explicitly has an explanatory structure of Newtonian mechanics, by which the cause of change in motion is explained by the concept of force.

Park and Han (2002) believed in order to successfully use deductive reasoning for changing students' conceptions about the direction of the net force acting on a moving object, three types of preventing factors (P1, P2, and P3 type) should be considered in classroom teaching. That is, classroom activities for understanding the explanation E1 (Explanation of the premises using instructional aids) and E2 (Explanation of the syllogistic structure of the task) should be developed for and applied to students' learning processes. Furthermore, science teachers should encourage students to think logically when they let them explain certain physical phenomena. Especially, as mentioned earlier, learning activities for understanding the above 4 statements corresponding to the general law of motion (which corresponds to the premise 1), and for determining whether the speed and direction of motion of object is changing or not (which corresponds to premise 2), should be necessarily designed for classroom teaching.

Park and Han (2002) described the conditions for arriving at a logically valid conclusion and for changing the students' prior conception through DET as follows: (1) Subjects should read the premises carefully and recognize that the conclusion can be drawn logically from the given premises. (2) Premises should be plausible and understandable to the subjects. (3) The syllogistic structure of the premises should be recognized by the subjects. (4) Subjects should draw conclusions based on the given premises rather than their prior beliefs or expectations. This study did not confirm if the change in conception was stable or temporary.

This small study reached for broad generalizations. With a small sample size from outside of the US such generalizations may not transfer. In addition, the results are only applicable to Newtonian physics. However, the idea that students must understand the premises to an argument before it will be plausible to them is not surprising and may be quite generalizable.

Conceptual Change and the NOS

Many researchers have also argued that in order for any instructional strategy aimed at promoting conceptual change to be effective, students must believe scientific theories are ideas and explanations, rather than facts set in stone. Solomon et al. (1992) included the history of science in instruction to help students better understand the nature of science and promote conceptual change learning. Lin et. al (2004) studied students' problem solving ability and found student beliefs about the NOS was the best predictor of this ability. Hart et al. (2000) switched the purpose of lab experiment from getting results to further content knowledge, to conducting experiments to investigate and communicate results, then examined student understanding of the NOS. Songer and Lin (1991) characterized students' beliefs about the nature of science to assess the relationship between these beliefs and students' propensity to integrate knowledge of thermodynamics. However, McCleary and Tindal (1999) used explicit, rule-based, concept anchored instruction and small steps to construct students' knowledge of the scientific method.

Solomon et al. (1992) qualitatively analyzed 400 middle school pupils’ responses to a questionnaire, and incorporated data from two investigations carried out by graduate students in their department to construct a theoretical perspective. This data was used to understand and monitor students' perceptions about the nature of science (NOS) while learning about the history of science. The investigations included students' drawings of scientists and interviews about these pictures, and free writing responses about scientists’ reasons and expectations for experiments. For the classroom study, teachers from five classrooms, located in three geographically diverse locations in Britain, were included as co-researchers. A researcher worked alongside the teacher on a regular basis. Elements from three different research methodologies, including intervention study, action research, and experimental research, were used to collect data and increase coherence.

The combination of intervention research and action research in Solomon et al.'s (1992) study did not allow for the usual monitoring and judgmental observation of all of the actors involved. However, careful note of the teachers' perceptions and recommendations were made. The preliminary questionnaire data resembled that of objective experimental research, the action research was guided by pupil interviews in addition to the questionnaire. Collaborative action research in the form of support and help for the teachers during the lessons ended with the final interviews by the researchers for the purpose of collecting impartial, objective data on pupil progress.

Data from the interviews were based on students' responses to the questionnaire. Solomon et al. (1992) found some students stuck with one view about the role of experiment and theory, while others used several. The results from the questionnaire were supported by interview data. Solomon et al. (1992), after comparing scores obtained at the beginning and end of the course and corroborating them with interview data, found a significant shift in students seeing the purpose of experiment as a way to try out explanations, rather than making a discovery. Also, more students thought scientists knew what to expect from an experiment, and fewer students thought of scientific theories as ideas or explanations, rather than facts. The authors attributed these findings to studying theories in the controversial context from which they arose, helping students to focus on the reasons for accepting or rejecting a theory, and presenting the historical perspective making conceptual change easier for students to accommodate. However, much of the improvement may have stemmed from the extra help available, new learning materials, and innovation enthusiasm on the part of the authors (Hawthorne effect).

Lin et al. (2004) found students' views of the nature of the scientific method appeared to be the best predictor for student problem-solving ability, explaining about 22% of the variance (N = 620). In addition, the researchers found the problem solving strategies of the students who scored highly on the nature of science survey were also more conceptually based. Internal validity of this study relied on the reliability of the conceptual problem solving tests. The first test covered pressure, density, buoyancy, and heat and temperature. The concepts included in the second test were: atoms, molecules, atomic weights, molecular weights, and chemical reactions. The seven items in the first test produced a Cronbach alpha of 0.74. The five items in the second test were 0.70 on the reliability scale. All of the items in these two tests required students to apply appropriate concepts to explain or predict a phenomenon. The content validity was assured by asking two faculty chemists, two science educators, and two high school science teachers to rate the degree of representation in the content covered, the readability, and the clarity of the items.

Internal validity in Lin et al.'s (2004) study also was based on the nature of science (NOS) questionnaire which twice scored a reliability rating greater than 0.83, and was supported by student interviews. The NOS questionnaire consisted of 53 statement items on a five-point Likert scale, with 1 standing for strongly agree and 5 standing for strongly disagree.

Most prediction studies have conducted regression using a single dependent variable once only. This study selected conceptual problem-solving ability as the dependent variable and collected the data twice in one year. The comparison of the two regressional results gave the researchers greater confidence in drawing the conclusion about the relationship between student understanding about the NOS and their conceptual problem-solving ability.

Participants of Lin et al.'s (2004) study included 620 year eight students and represented typical Southern Taiwan junior high students. Students were categorized as post-positivist-oriented or empiricist aligned based on their score on the NOS survey. Students were also assigned as high academic achievers or low academic achievers based on their first mid-term test result. In both of the classifications, the cut-off point was the median score.

Lin et al. (2004) found the post-positivist students (mean = 9.96, standard deviation = 4.58) outperformed their counterparts (mean = 6.49, standard deviation = 4.03) significantly ($p < 0.001$) on the first conceptual problem-solving test. A similar result was obtained when the statistical analysis *t*-test was used on the second conceptual problem-solving test.

The qualitative results of this study revealed that students with different scientific epistemological beliefs perform differently in their conceptual problem-solving strategies. The post-positivist-oriented students were able to apply reasoning skills in organizing the related concepts retrieved from their knowledge structure. The empiricist-aligned students tend to grab the numbers and statements in the problem and perform blind mathematical calculations without checking the appropriateness of the calculations, and simply ignore the relationship between the related concepts to the problem.

Despite the fact that the follow-up interviews were limited to four students solving only two test items, this study provides both quantitative and qualitative evidence that students' understanding about the NOS is strongly related to their problem-solving strategies. This result lends support to the argument by the American Association for the Advancement of Science (1991) that promoting students' understanding of the NOS is important because better understanding of the NOS might result in higher conceptual problem-solving ability. In addition, the knowledge of what subscale of the NOS is related to the conceptual problem-solving ability is helpful, since it provides a way of measuring improvement of that ability. The results of this study may encourage curricular developers to focus more on the nature of the scientific method. However, mean scores of a Likert scale were used to evaluate the NOS survey results. In addition, this is a correlational study, which only shows problem solving ability and epistemological beliefs are related but one may be a side effect of the other and other factors may play an equally important role.

Although the mechanism of how and why thorough understanding of NOS results in better achievement in conceptual problem solving needs to be scrutinized. This difference can be partly explained by the findings of Songer and Linn (1991) and Hart et al. (2000). In Songer and Linn's (1991) study, it was found that the students who view science as static assert that science consists of a group of facts that are best memorized. On the other hand, those who view science as dynamic believe that scientific ideas develop and change, and that the best way to learn these ideas is to understand what they mean and how they are related.

"Thus, observation is not a matter of passively receiving information about the natural world. People will see different things according to their expectations, and theoretical frameworks they hold. In pretending otherwise, school science leaves out many crucial aspects of scientific activity, including fallibility, the passion, the commitment, and the creativity involved" (Hart et al., 2000, p 658).

Hart et al. (2000) studied how switching the purpose of lab experiments from getting results to further content knowledge, to conducting experiments to develop, verify procedures and results, and communicate, as is done in the real scientific community, shaped students' learning and attitude about the course over a six week period covering one unit.

Hart et al. (2000) incorporated classroom observations and notes, a class survey, copies of student work, interviews form 10 students, and lab group interviews to document student learning. Results form the survey administered halfway through the unit indicated students enjoyed experimental work involving chemicals (21 of 22), and 10 of the 22 students believed the purpose was to observe chemical reactions. Six of the 22 students believed the purpose of the experiments was to design and follow a flow chart. Four of the students thought gaining experience in the lab, using the equipment, and writing a report was the purpose. Only one student clued into the teacher's primary purpose which was to give students insight into how scientific knowledge is established and the nature of experimentation. In response to questions about student-teacher/physicist talk, 10 of 20 students did not see a connection between the talk and the experiments. Five of the students only connected the experiments with the talk because they were both physics related.

At the end of the unit, Hart et al. (2000) found 11 of the 22 students were given audiotaped interviews in their lab groups. Student responses showed significant shifts in their beliefs about the experiments. Three of the four groups made the link between the experiments done in class and scientists' work. The fourth group included a student new to the school and one who has struggled in science in the past. These students believed the purpose was to learn the proper procedures for conducting experiments in school, rather than making connections with the work of scientists.

Hart et al. (2000) found students to better understand the nature of science and how scientific facts are established, including the fallibility, passion, commitment, and creativity involved in scientific work, and experience the role of the scientist. The conceptual understanding students gleaned in terms of content knowledge was not measured or discussed. However this study did portray a science classroom in which students (all girls) were, in Dewey's terms, wholeheartedly experiencing genuine science. This experience was not without significant difficulty in terms of safety, time, organization, set-up, and teacher support needed to make this a successful experience.

The students' experience lasted six weeks (one unit), it would be most interesting to see if the experience had any affect on students' learning in future classes. Would students be more likely to engage in meaningful learning? Other research (Lin et al., 2004; Pugh, 2002; Solomon et al., 1992; Songer & Lin, 1991); and Tsai, 2000) has suggested when students view the nature of science in terms like those from the Hart et al. (2000) quote above, students will choose to learn in more meaningful ways, thus more likely to achieve conceptual understanding. The purpose of the unit studied was not to directly enhance content knowledge but to enhance knowledge about the nature of science. This study presented one way on possibly enhancing this knowledge. This was a small study that did not incorporate the use of a control group, random selection, or careful analysis. More research is needed before generalizations can be made about students learning about the nature of science in the format presented here.

Songer and Linn (1991) set out to characterize eighth grade physical science students' (N= 153) beliefs about the nature of science, to assess the relationship between these beliefs and students' propensity to integrate knowledge of thermodynamics, to examine the effectiveness of principles and prototypes as loci of knowledge integration, and to determine which knowledge integration aid students prefer as they used Computer as Lab Partner (CLP) curriculum. The curriculum emphasizes hands-on experiments using computers that are on line to real-time data-collection devices.

Songer and Linn (1991) also emphasized the development of integrated understandings of the concepts of heat energy and temperature through integration interventions. These interventions included on-line integration interventions at the conclusion of each experiment, which were identical for all students, and also off-line integration interventions that varied with each of three class groups. The off-line integration interventions included worksheets related to the experiments and integration homework. The loci of integration were divided between the six classes. Two classes were instructed to integrate the experiments around principles, two around prototypes, and two around both principles and prototypes.

In addition to dividing the class into three separate treatment groups, Songer and Linn (1991) classified students using The Views of Science Evaluation, into three science beliefs categories. These included dynamic beliefs group (15%), static beliefs group (21%), and mixed beliefs group (remaining 64%). Two other tests were used to measure isolated and integrated knowledge, and students' ability to integrate knowledge from classroom and natural world contexts.

Songer and Linn (1991) found no statistical difference was found between the ability of students with dynamic beliefs about science and static beliefs about science to integrate information around principles and prototypes ($n=137$, $p < 0.21$). However, an ANOVA comparing the three belief groups' success at integration of knowledge found category of science belief to have had a significant effect ($p < 0.01$), with scores from dynamic beliefs students ($m = 4.15$, $SD = 1.05$) exceeding those of static belief students ($m = 3.03$, $SD = 1.45$). In terms of loci preferences, no differences between the three belief groups were noted. In general students reported preference to the use of whichever mode they had been assigned to.

Songer and Linn (1991) concluded students are likely to gain more integrated understanding of science if their courses offer students a range of loci and emphasize both knowledge integration and knowledge about the nature of science. They suggest this must be done with instructional interventions specifically focusing on integration, rather than isolated scientific ideas. These suggestions are well founded based on the results of their careful research and analysis. However, student beliefs may be an effect of their knowledge integration skills rather than a precursor to this ability. Either way, this study shows learning is enhanced when students are encouraged to integrate knowledge into a dynamic belief system.

McCleary and Tindal (1999) implemented two experimental conditions in a sixth-grade general education science classroom with one control group to examine the effect of explicit, concept -anchored instruction on promoting science literacy. This first experimental condition was a pull-away group whose members ($N = 6$) were chosen randomly from a list of students at-risk for failing period A. This group was evenly divided with regard to sex, and four of the six students were classified as learning disabled. This group received five, 40-minute sessions over the six-week unit on the scientific method. During these sessions, students were taught by one of the researchers, a former teacher from that school, with a conceptually based, explicit instruction with rules. A more in-depth description of this instruction will follow. The second experimental group included the rest of the students of period A, from which the pullout group was formed (N = 23). This group was approximately 75% male and six of the students received special education. This group received the same hands-on constructivist instruction as the control group, except the final experimental lab and outcome measure would be administered by the trained teacher/researcher. The control group (N = 28) was more balanced with regard to sex, and four of these students received special education services.

Science literacy was defined in this study as including the same three components as the AAAS, NSTA, and NSF have proposed. These components include: knowledge of concepts within content discipline areas, application of science process skills, and use of high-level reasoning within instruction. The scientific method unit for the pull-away group was framed around the following six key concepts: experiment, problem, hypothesis, testing and procedures, measurement and tools, and data/explanation.

In McCleary and Tindal's (1999) study, the treatment curriculum for the pull-away group consisted of each concept and its attributes explicitly taught through small steps guided practice, and successful practice using examples and non-examples. Students used an outline to structure a series of rules to guide student learning of the scientific method and construction of a scientific explanation. Throughout the instruction, the teacher was said to have engaged the students in higher-level reasoning about the experiments focused around the same concepts as Periods A and B.

The hands-on constructivist activities in Periods A and B engaged students in experiments using these concepts. It should be noted that it is unclear why the author classifies the regular instruction as “hands-on constructivist.” McCleary and Tindal's (1999) description of this class includes a long opening non-science oriented discussion related to current events, followed by a brief introduction of the day's experiment, notes on the board outlining the experiment, students conducting the experiment in groups of three to five, clean-up, and any remaining time is for homework out of the book. If experiments are conducted quite regularly, then yes the instruction is “hands-on”. However, the means for construction of students' knowledge remains unclear. From a sociocultural constructivist perspective, students complete individual worksheets and do not have whole group discussions, or presentations to discuss findings and initiate cognitive conflict or encourage “construction” of knowledge.

McCleary and Tindal's (1999) final assessment was based on the scientific explanation students gave, pertaining to a lab that was the same for all groups. However, different teachers gave the assessment and the prompts were different for the control and treatment groups. A base line from which to compare the findings with the final assessment had established that none of the students provided an explanation on the baseline experiment. In addition, the academic ability and conceptual understanding of the scientific method was not adequately measured and compared between the classes. Due to the lack of an adequate base line and inconsistencies with assessment, the results are quite suspect and not reported in detail. In general, the researchers found the pull-away group and Period A to perform significantly better than the control group on nearly all areas measured. In addition to research over sites, the results from the pull out group and period A could simply reflect the reduction in class size.

This line of research is worth pursuing in a more careful fashion. Construction of knowledge does require instruction; it is unlikely to occur without careful guidance. The structure of this instruction, and the extent to which it needs to be explicitly taught under rigid rules and guidelines, is still up for debate.

Conceptual Change and Motivation

Zusho and Pintrich (2003) investigated the role of certain motivational components and their relation to students' learning and achievement outcomes in two college chemistry courses. Participants were 458 students enrolled in introductory college chemistry classes at a large Midwestern university in the USA. The majority of these students were Caucasian freshmen or sophomores. The following research questions were the focus of this study: First, how does motivation change in chemistry over the course of one semester? Second, how does strategy use change in chemistry? Third, how do the motivational and cognitive components predict performance in chemistry?

Zusho and Pintrich (2003) analyzed data in the form of students' self reports on three surveys (time one, two, and three) and background information included SAT scores, self-efficacy, task value beliefs, goal orientations, interest, anxiety, and their use of various cognitive and self-regulatory strategies. In addition, students' grades were collected at the end of the semester as a measure of participants' course performance. Students' grades in both courses were calculated based a point system, thus eliminating the need to standardize test scores across the two courses. The tests consisted of both open-ended and close-ended questions. Open-ended questions included short case studies drawn from pharmaceutical chemistry or materials science that required students to represent their understanding of the chemical phenomenon in multiple ways; for example, through numbers, words, pictures, and graphs. Close-ended questions were typically of multiple-choice format, and emphasized a range of recognition and reasoning skills.

The components of student learning focused on in Zusho and Pintrich's (2003) study included motivational processes, cognitive processes, and outcomes. Within these components, there were four motivational aspects of concern. These included self efficacy (students' judgments of their capabilities to perform a task, as well as their beliefs about their agency in the course), value beliefs (students' beliefs about the utility and importance of a course); goal orientation (individuals' purposes when approaching, engaging in, and responding to achievement situations); and affect (personal interest and anxiety).

In terms of cognitive processes, Zusho and Pintrich (2003) were mainly concerned with students' self reported use of specific cognitive and self-regulatory strategies including rehearsal-- a surface level strategy, where students focus on memorizing and recall of facts; elaboration-- a deeper processing strategy, where students focus on extracting meaning, summarizing, or paraphrasing; and organization, another deeper processing strategy, where students focus on organizing material through the use of outlines or drawing maps. Self-regulatory strategies can be defined as those strategies that help students focus on planning, monitoring, and controlling their cognition. Such strategies can take the form of self-testing, monitoring of one's understanding of course content, or repairing one's understanding by re-reading or doing more problems.

Zusho and Pintrich's (2003) results showed an overall decline in students' motivational levels over time, specifically there was a decline in students' level of self-efficacy ($F(2,443) = 15.10, p < 0.001$). Task value, too, declined over the course of the semester ($F(2, 443) = 91.40, p < 0.001$), as did students' endorsement of performance goals ($F(1, 440) = 11.662$, $p < 0.001$). There was also a decline in students' use of rehearsal strategies ($F(1,452) = 77.51$, $p < 0.001$) and elaborative strategies ($F(1, 451) = 180.77$, $p < 0.001$), while students' use of organizational ($F(1, 449) = 251.92$, $p < 0.001$) and metacognitive strategies ($F(1,405) = 18.01$, $p < 0.001$) increased from time 2 to time 3. These trends, however, were found to vary by students' achievement levels. There were no significant differences in students' reports of their mastery goals, interest, and anxiety over time. In terms of the relations of motivation and cognition to achievement, the motivational components of self-efficacy and task value were found to be the best predictors of final course performance even after controlling for prior achievement.

Zusho and Pintrich (2003) found adaptive motivational beliefs such as self-efficacy, task value, and mastery goals were positively related with final course points, while maladaptive motivational beliefs such as anxiety were negatively related with final grade. Contrary to the authors' expectations, use of rehearsal strategies was related positively with achievement. In terms of the relations between motivation and cognitive strategy use, in line with past research findings, students with higher levels of self-efficacy, task value, and mastery goals also reported using deeper-processing cognitive strategies such as elaboration and metacognition. However, these same students also reported using rehearsal strategies, especially at time two.

Zusho and Pintrich (2003) believed there were no main effects of performance for performance goal orientation, organization, and elaboration. There were, however, several significant performances by time interactions. More specifically, students' ratings of their levels of self-efficacy varied by performance, with high-achieving students' self-efficacy levels increasing over time and low-achieving students' self-efficacy levels decreasing over time ($F(4,420) = 22.99$, $p < 0.001$).

Zusho and Pintrich (2003) realized a similar pattern emerged for task value, although there was no discernible difference between average-achieving and high-achieving students' ratings of task value at time 1 (F (4, 418) = 9.764, $p < 0.001$). Students' ratings of their interest also varied by their achievement levels; not surprisingly, high achievers expressed increasingly higher levels of interest over time than did both average-achieving and low-achieving students (F (2, 427) = 3.213, $p < 0.05$). Low achievers' level of interest actually decreased from time two to three.

In addition, Zusho and Pintrich (2003) asserted there were two interaction effects for two of the cognitive strategy use variables; specifically, rehearsal and elaboration. First, in terms of rehearsal strategy use, high achievers reported using significantly more rehearsal strategies at time two than average and low achievers. However, their use of rehearsal strategies decreased dramatically at time 3, with more average achievers reporting using rehearsal strategies at time three than high achievers (F (2, 427) = 9.146, $p < 0.001$).

In light of the research linking use of deeper cognitive strategies and self-regulatory strategies to improved learning outcomes, this finding was encouraging. As for the correlates of success in college chemistry, not surprisingly, students with a history of academic success were more likely to obtain higher scores in chemistry. More importantly, however, Zusho and Pintrich (2003) suggest that students with adaptive motivational beliefs (i.e. students who have high levels of self-efficacy and task value) ultimately do well. In fact, students' ratings of their levels of self-efficacy and task value at time three were better predictors of final course performance than their SAT-mathematics scores. Additionally, it was found that students who employed rehearsal strategies also did well in the course.

Taken together, Zusho and Pintrich (2003) suggested these findings show that it would indeed be remiss to ignore issues related to students' motivation and affect in the study of students' science learning. As Pintrich et al. (1993) stated, it is not enough to examine issues related to students' 'cold' conceptual change. Educators must also consider how students' motivational processes such as self-efficacy and task value influence the learning process. There are several implications of this study. First, it is important to facilitate adaptive motivational beliefs. For example, one can help maintain self-efficacy levels by communicating the role of effort and strategies. In other words, it is essential for instructors to convey to students that chemistry is indeed learnable, and that one can increase one's knowledge and skill of chemistry by employing specific strategies. It is also vital for chemistry instructors to focus on task value in their pedagogy and explanations of course material, as well as relate instruction and assessment to the relevance and utility of chemistry for everyday life. Second, it is important to facilitate strategy use. Instructors might consider modeling specific strategies or ways of thinking for learning chemistry in class, in addition to encouraging students to share their own strategies for learning the course content.

The population of this study was mainly Caucasian college students. It would be interesting to investigate these questions with a younger and/or more diverse population. The results of this study were carefully analyzed and supported by other research. Zusho and Pintrich's (2003) suggestions could be generalizable to similar populations and further research based on their findings could shed light onto why college chemistry classes are often mostly Caucasian.

Metacognition

Case and Gunstone (2002) adapted a chemical engineering course to promote deep approaches to learning by promoting metacognitive development, defined as a shift in a student' approach to learning. Chin and Brown (2000) qualitatively compared and detailed the differences between learning science through predicting, self-explaining, and metacognition. The use of these strategies produced differences in the generative thinking, nature of explanations, asking of questions, metacognitive activity, and approach to tasks associated with a deep approach to learning.

Case and Gunstone (2002) studied the metacognitive development—defined as a shift in a student' approach to learning-- in a South African college chemical engineering course. The course was adapted to promote deep approaches to learning by promoting metacognitive development. Adaptations included a 25% reduction in content covered, teaching methods to promote active learning during lectures (peer discussion and problem solving), and an increase in conceptual items in assessments (open ended qualitative questions). In addition, memorization was de-emphasized by allowing students a 'crib sheet' to all tests and examinations where they could write any information the chose. One test was given with an 'unlimited time' format so students could focus on the concepts without time stresses. Metacognitive development was encouraged through the use of weekly journal tasks, and explicit discussion of issues relating to learning and conceptual understanding in the lectures.

Case and Gunstone's (2002) study included data from at least five in depth, audio taped and transcribed, interviews complimented by other data including students' journal entries (N=11). These students were selected from the class list by means of a purposive sampling technique in which maximum diversity based on race, gender, and first year grades was sought The researchers believed these characteristics would be likely to give the greatest variety of perspectives on the course, rather than a form of causal variables against which hypotheses were to be tested. A factor which somewhat limited the achievement of maximum diversity in the sample was the decision to approach students in the self-selected groups of three in which they worked in the tutorial sessions. However this appeared to reduce the awkwardness of being approached, and outweighed this disadvantage. The students in four groups were approached and all agreed to participate in the study. One student changed her course of study in the first week of term, and the final sample therefore comprised 11 students.

Case and Gunstone (2002) aimed audiotaped and transcribed interviews at getting students to talk specifically about their experience of the course as they went along. Questions were formulated around specific incidents that had happened in class, tasks that had been given, tests that they had done, and so on. Student data from journals and interviews were classified into ‘self-reflective data’, in which students reflected on their experience of the course, and ‘conceptual data’, in which students revealed their understanding of concepts as they engaged with particular tasks. Additional conceptual data came from test and examinations.

Case and Gunstone's (2002) data analysis took place in four distinct stages. The first stage took place as the data were being collected during the first semester, and involved a process of ‘open coding’ in which common themes were noted as well as issues for further exploration. The second stage occurred during the university vacation, and involved a preliminary pen-and-paper analysis of the data collected during the semester. In this process a preliminary set of categories describing students' approaches to learning was developed, and data from each student coded accordingly. Areas needing further exploration were flagged for follow-up in the final interview(s). The third stage followed these interviews, and involved fitting the recent data into the categories established in the preliminary analysis, and refining these categories accordingly. In the final stage of analysis, all the data were recoded from scratch using the categories (approaches) and subcategories (describing aspects of approaches) that had been developed in the preliminary analysis. This process was facilitated by the use of the NUD*IST software package. Once all the data had been assigned to particular categories, a process of 'axial coding' took place, in which the data in each category was assessed against the properties of that category. The final result of this analysis was for each individual student a description of the approaches to learning used at different stages in the course was given. This allowed an assessment of the degree of metacognitive development (shift in approach to learning) that took place.

Case and Gunstone (2002) found these students fell into one of three categories. These included: (a) those who were using a conceptual approach from the start of the course; (b) those who began with an algorithmic approach and made some degree of change towards a conceptual approach; and (c) those who initially utilized an information-based approach and did not show any appreciable change in their approach to learning during this course.

Of the eleven students, Case and Gunstone (2002) found four were believed to use the conceptual approach from the beginning, four began with an algorithmic approach and moved towards a conceptual approach, and three used an information-based approach for the duration. Three of the four students in the second group failed the course, as did the latter three students. Students who used a conceptual approach from the start of the course realized a conceptual approach was essential for success and focused on working through examples on their own to develop their own problem solving methods and build conceptual understanding. All of these students were successful in the course. The students who exhibited some shift in metacognitive development did so at different stages in the course, only the student who exhibited a shift early in the course was successful at its completion. The last group was seen as unaware of the need to make a change in approach to learning and never tried.

From these results, Case and Gunstone (2002) evaluated possible aspects of the course that were, or were not, supportive of metacognitive development and conceptual understanding. Students who already used the conceptual approach found the teaching and assessment supportive of this type of learning. Those who exhibited some shift in metacognitive development in the course named the unlimited time on the tests and journal tasks as supportive of their development. Students actively engaged in the conceptual approach were able to gain the most from completing an unstructured concept map. However, the heavy workload and time constraints during some of the assessments were found to be detrimental to metacognitive development.

This small study highlights the difficulty students can have when course expectations shift from algorithmic to conceptual and achieving this shift is essential to success in the course. Such difficulty shows both a lack of such expectations from earlier educational experiences and the need for such expectations to begin in early educational experiences. It may also serve as a lesson for teachers trying to change expectations in their classrooms from algorithmic to conceptual that it requires not only content knowledge on the part of the teacher and student but also metacognitive development. This process may be slow and come with some student resistance. Research on school-wide or district wide shifts towards conceptually based expectations with the support of teacher and student metacognitive development would be ideal. Although this study was small, data was carefully coded and analyzed and worth attention in future studies.

Chin and Brown (2000) studied six, eighth grade students whose learning approaches ranged from deep to surface level to qualitatively compare and detail the differences between learning science with these approaches. The research was part of a larger study the Learning Approach Questionnaire, which measured students' tendency to learn meaningfully using a deep approach or by rote using a surface approach. The questionnaire used a 5-point Likert scale to categorize students into learning approach groups. The students were asked to base their responses in the context of the science classroom. References to learning approaches were not made in the questionnaire to prevent students from being clued into their particular learning approach. The Cronbach alpha reliability coefficients of internal consistency for the meaning orientation and reproducing orientation scales were 0.86 and 0.65 respectively. Test-retest reliabilities over a nine-day period were .86 and .80, respectively, for these two scales. The six students chosen were from the same class and represented learners using learning approaches that ranged form deep to surface, based on the questionnaire and the teacher's evaluation. Of the six students, three were boys and three were girls, and there was both a male and female representative of each a deep, surface, and combined approach use.

Based on the teacher's prior success with same sex groups, the students were placed into groups based on sex. The female group was videotaped and the male group was audio taped over a nine-week chemistry unit. Each student in the group of six was also interviewed (audio taped) before and after the nine-week unit on their understanding of science concepts from the unit and reasoning behind them. Field notes on classroom discourse and activities were also taken. The interview and group discourse transcripts were analyzed using an iterative process beginning with several readings to get a sense of the totality of the data. This was followed by identifying several coding segments and then inductively deriving coding categories. A constant comparative method was used to cluster codes into progressively more inclusive categories. Working back and forth among the data from the various sources helped Chin and Brown (2000) detect relationships among the categories and refine the working hypotheses, on the basis of confirming and disconfirming evidence.

From analysis of the data, Chin and Brown (2000) found five categories emerged as meaningful perspectives that would illuminate the differences between deep and surface approaches to learning. These included (1) generative thinking, (2) nature of explanations, (3) asking questions, (4) metacognitive activity, and (5) approach to tasks. These categories formed the framework for comparing and contrasting deep and surface approaches to learning. Generative thinking was defined as the ability to generate an answer when a ready-made fact recall based response was not available. Students using a deep approach used chain reaction thinking often based on prior knowledge using more precise language. Surface approach students gave up more easily, responded vaguely, and in more of a piecemeal fashion. The natures of explanations were categorized into four types ranging from reformulating the question (surface approach) to describing nonobservable, theoretical entities-- “microscopic explanations”. To generate microscopic explanations, Chin and Brown (2000) found students often used mental imagery, analogies, real-life experiences, or hypothetical examples to articulate their ideas. Surface approach questions referred to more basic factual and procedural knowledge than deep approach questions, which tended to be wonderment questions. Metacognitive activity included students' use of comprehension monitoring and evaluative strategies indicating reflection on the learning process and their comprehension. The more this occurred, the deeper the approach to learning. Students with a deep learning approach also were more persistent in following up ideas with sustained interest before moving on to another one, whereas those using a surface approach might give up on an idea as soon as it doesn't work.

Triangulation of data from multiple sources allowed Chin and Brown (2000) to credibly assert that for students using a surface approach, strategies for a deep approach are less accessible to them than for students who regularly use a deep approach to learning. These deep learning strategies include predicting, self-explaining, and metacognition. The use of these strategies produced differences in the generative thinking, nature of explanations, asking of questions, metacognitive activity, and approach to tasks associated with a deep approach to learning. The authors claim the use of the aforementioned strategies, for some students, are only manifested under optimal conditions. For this reason, the authors suggest teachers should develop optimal conditions by scaffolding students' thinking with prompts, and encouraging students to ask questions, predict, explain and elaborate during activities and discussions.

This study examined the nature of students' learning approach at a more fine-grained level than other more general, performance-based studies. The analysis of students' thinking processes, and cognitive and metacognitive strategies allow for the identification and articulation of finer differences between deep and surface approaches to learning in the context of a science class. The data was collected from a variety of sources including written and tasks and interviews that were corroborated by student engagement with hands-on activities carried out during regular science classes. The triangulation of data, careful coding and analysis, and the context of a natural setting add significant credibility to the research. With strategies and differences between deep and surface approaches defined, further research can examine the effects of teaching strategies aimed at inducing a deep approach to learning.

Meaningful Learning and Conceptual Understanding

Pugh (2002) examined two teaching styles, one case based, one ideas based, and their propensity to foster transformative experiences. He used Dewey's definition of transformative experience--an expansion of perception and value resulting from active use of a concept. The three key qualities of a transformative experience are 1) active use of the concept, 2) an expansion of perception, and 3) an expansion of value. For the purposes of this study, active use was defined as talking to other people about the class concepts when outside of class and thinking about or seeing examples of the concepts when outside of class. Pugh (2002) believed this type of experience may be elicited through teaching methods that display how a concept functions as a true idea for the teacher by modeling everyday use of the concept to more fully perceive the world and by modeling the excitement or satisfaction that comes from doing so. The teacher would also provide supported opportunities for students to use the concept to expand perception, first in-class and then out-of-class. The goal is to help students move from having in-class, supported experiences with the concept to having out-of-class transformative experiences. Pugh believed there was potential for this to be accomplished through the specific modeling and scaffolding of use, perception, and value on the part of the teacher. This formed the basis of the idea- based treatment curriculum. A case-based curriculum served as the control teaching method.

Pugh's (2002) small-scale, exploratory study examined the effectiveness of two teaching elements (the artistic crafting of content and the modeling and scaffolding of perception and value) at fostering transformative experiences.   The elements were used in teaching a unit on adaptation and evolution in a predominantly tenth grade, high school zoology class. Student outcomes were compared with those of students in a roughly equivalent (as determined by a preintervention survey) class in which the same unit was taught using a case-based model of instruction.

This study took place in a large, suburban high school in the Midwest. Prior to the intervention, both classes had been taught by a veteran teacher who de-emphasized vocabulary and facts and focused on the development of conceptual understanding and inquiry skills. The main classroom activities were lab work and class discussion. However, lectures were included on a regular basis. The teacher organized the zoology class around a series of veterinarian case studies. The intervention was introduced about a month and a half into the semester. Hence the students were accustomed to participating in a progressive type of school context, which emphasized student involvement, understanding, inquiry, and real-world application.

Pugh (2002) chose one of the zoology classes as the experimental condition. This class had a total of 17 students, 53% female and 6% minorities. The comparison class had a total of 22, 45% female and 5% minorities. Both approaches may be considered progressive in that they emphasize student activity in the form of class discussion and engagement in group projects and lab activities and both approaches involved a deliberate structuring of content and use of modeling and scaffolding. However, the specific nature of the content structuring and the modeling and scaffolding differed.

In the idea-based class, Pugh (2002) organized the content around an artistic crafting of content—around an attempt to present the significance of the concepts and their ability to transform perception and value. In the case-based class, content was structured around an endangered species case study. Hence, in the idea-based class, the researcher presented the concepts directly as compelling ideas, and tried to emphasize what was so compelling about them and how they could lead to transformative experiences. In the case-based class, the concepts emerged out of the students' inquiry into the problem of endangered species, and the researcher merely helped to formalize the students understanding while also guiding their inquiry.

Pugh (2002) pre-assessed situational interest and conceptual understanding with a Likert scale test and open-ended questions. The purpose of this assessment was to assert the case-based as "good" instruction that can be used to compare against the ideas based instruction. A postintervention survey was administered at the conclusion of the intervention. This survey contained six Likert scale items assessing students' interest in the concepts of adaptation and evolution as well as their perception of the worthwhileness of learning these concepts. An assessment of understanding, consisting of six open-response items, was also given at the conclusion of the intervention. These items were designed to assess students' conceptual understanding. A month after the intervention, a follow-up assessment of understanding was administered. This assessment contained two open-response items similar to those on the prior assessment of understanding. At the same time, a follow-up survey was administered. This survey contained four items assessing everyday use of the concepts and four items assessing students' interest in the concepts and two items assessing the degree to which students value the concepts because they expanded their perception. Students responded to these items by marking the appropriate category on a 6-point Likert scale. As additional data sources, the classrooms were videotaped, and post intervention interviews were conducted with some students.

Overall, Pugh (2002) found students in the idea-based class were able to accurately describe and apply the concept of adaptation; however, they still had some misunderstandings regarding the evolutionary processes by which adaptations come about. The mean score for the class was 43.4 on a scale of 58 (SD =6.2). The mean for students in the case-based class was also 43.4 (SD = 8.1).

Pugh (2002) found all 17 of the participating students in ideas-based class and 18 of the 22 participating students in the case-based class completed an in-class writing activity. In the idea-based class, 71% of the students were able to describe at least one valid experience of seeing, thinking about, or talking with others about adaptations or endangered species. In contrast, only 17% of the students in the case-based class described at least one valid example. Moreover, 12% of the students in the idea-based class gave multiple examples, whereas none gave multiple examples in the case-based class. The difference between classes was significant (U (N = 35) = 67.5, p < .01).

Twelve students in Pugh's (2002) idea-based class and 19 students in the case-based class were able to attend the zoo trip. Of the students in the idea-based class who attended, 25% reported that their perception had changed in that they now thought about the animals in terms of adaptation or evolution. No significant differences were found between the two classes on responses to the zoo survey. However, on three of the four items, there was a difference of more than 20 percentage points, with the idea-based class having a greater percentage. These three items assess active use and expansion of perception. Hence, taken together, they provide a trend suggesting that a slightly greater percentage of students in the idea-based class may have actively used the concepts and experienced an expansion of perception while at the zoo.

Pugh's (2002) results indicate that a significantly greater percentage of students in the experimental class (52.9%) than students in the control class (22.7%) engaged in some degree of transformative experience. Further, it was found that students from both classes who engaged in at least some form of transformative experience scored significantly higher than other students on a follow-up assessment of understanding but not on a post intervention assessment of understanding.

Pugh (2002) found there were significant differences between the two classes in terms of reported use of the concepts in everyday life. Students in the idea-based class reported that they talked to others about adaptations more frequently (U (N = 39) = 92.5, p < .01) and thought about or saw examples of adaptation more often (U (N = 39) = 73, p < .01). Likewise, students in the idea-based class reported that they talked to others about evolution more frequently (U (N = 38) = 98, p < .01) and thought about or saw examples of evolution more often (U (N = 38) = 109.5, $p < .05$). Idea-based class students were able to provide a greater number of valid descriptions of having thought about or seen examples of adaptation (U (N = 39) = 88, $p < .01$) and evolution (U (N = 38) = 139.5, $p < .05$). In addition, the proportion of students who reported an expansion of perception was far greater in the idea-based class than in the case-based class (76% compared with 32%) and the difference was statistically significant, (X^2 (2, N = 39) = 7.69, $p < .05$).

Pugh's (2002) results from the follow-up assessment showed, in terms of differences between classes, the idea-based class scored significantly higher on the active use of the concept of adaptation items (t (37) = 2.55, $p < .05$) but not on the active use of the concept of evolution items. No significant differences were found on the interest items or the valuing of the concepts because they expand perception items. Sixteen of the participating students in the idea-based class and 20 of the participating students in case-based class completed the follow-up assessment of understanding. Students in the idea-based class performed well on the adaptation item but poorer on the evolution item. Hence, on average, they seem to have maintained an understanding of the principle of adaptation, but their understanding of the evolutionary processes seems to have declined during the month following the intervention. Nevertheless, students in the idea-based class did score significantly higher on this assessment than students in the case-based class (t (34) = 2.56, $p < .05$).

Hence, the general trend in Pugh's (2002) data suggests that students in the idea-based class may have experienced a slightly greater expansion of value. Some students, in both the ideas-based and case-based classes, did experience this fusion. They actively used the concepts on a number of occasions, and this use led to a significant transformation of their perception. The students mentioned did not engage in the most dramatic level of a transformative experience, but they clearly did engage in genuine transformative experience. It should be noted that these results indicate the effectiveness of the two instructional elements taken together. The study does not indicate whether one of the elements had a greater impact on the results or whether either would be effective if taken separately.

Overall, Pugh (2002) asserted the results of this exploratory study support the theory that the two instructional elements help foster transformative experiences. Finally, one of the unexpected findings from the study was that the idea-based class scored higher on the follow-up assessment of understanding. This result was particularly surprising given the fact that both classes scored equally well on the assessment of understanding given at the conclusion of the intervention. This outcome raises the possibility that there exists a relationship between engagement in transformative experiences and enduring conceptual understanding. To further examine the possibility of a relationship between engagement in transformative experience and enduring conceptual understanding, Pugh compared the assessment scores of those (in both classes) who engaged in at least some form of transformative experience with those who did not. A one-sided t test revealed that the students who engaged in at least some form of transformative experience scored significantly higher on the follow-up assessment of understanding ($t\ (34) = 1.96$, $p < .05$) but not on the original assessment of understanding.

Pugh (2002) used the Mann-Whitney test to determine significant differences on the Likert scale and frequency items. The open-response items were coded into categories by two independent raters. Interrater reliability on all items was greater than 81. Two independent raters using a scoring rubric also coded responses to the assessments of understanding. Scores assigned by the two raters were averaged. Inter-rater reliability was greater than 74 for all items. For each assessment, the averaged scores on each item were summed and the t test was used to determine significant differences between classes. A two-sided test was used for the pretest items and control variables. A one-sided test was used for the experimental variables.

Because the differences between responses on the Likert scales were not equivalent, average scores may be unreliable as a measure of the students' true responses. In this study these averages were used to compare the two classes. If one class had many students to each extreme and the other had many who responded in the middle of the scale, one class may actually be serving a small minority very well whereas the other is somewhat appealing to the majority. This pattern did exist in the comparison of students' active use of items. In the case based class, 55% reported never talking with others outside of class about adaptation and 5% did this between 10 and 15 times. However, in the ideas based class, only 12% reported a never response and 0% reported a 10-15 times response, with the majority of the responses falling between 1-5 times. The average of Likert scale responses alone is not sufficient to compare the two classes. As mentioned earlier, the classrooms were also videotaped, and postintervention interviews were conducted with some students. One example of such an interview was given and information from this interview could be used to corroborate responses to the surveys. A larger study with more of an emphasis on observation methods, to add validity to survey results, would allow more substantial comparisons between ideas based and case based teaching methods for transformative experiences to be made.

Pasley et al. (2004) qualitatively assessed science lessons from a subset of middle schools from the schools that participated in the 2000 National Survey of Science and Mathematics Education to determine effective pedagogical techniques for engaging students in meaningful learning. An elementary and high school from the feeder pattern of each middle school were randomly selected and included in the study. Two science teachers were randomly selected from each school for classroom observations. One hundred and eighty lessons were studied. Systematic sampling and implicit stratification were used in selecting the schools included in the study.

Pasley et al. (2004) began the rating of the lessons with individual components and then the lesson was given an overall rating. The lessons were rated on a scale divided into the following levels: 1--ineffective instruction (a. passive learning, b. activity for activity's sake), 2--elements of effective instruction, 3—beginning stages of effective instruction, 4--accomplished, effective instruction, 5—exemplary instruction. Lessons given a rating of 1 generally lacked student engagement with important science because of developmental inappropriateness and a lack of connection between the activity and the concept. On the other hand, lessons with a high rating successfully provided opportunities for students to grapple with important science concepts in meaningful ways. Many lessons incorporated elements of exemplary teaching but during the execution of the lesson the teacher short circuited the learning process by moving too quickly, giving students the answer, or ridiculing students for asking unexpected questions. The researchers claimed to have results comparable to the 2000 National Survey and the examples of lessons given appeared to be appropriately rated.

Pasley et al. (2004) collected field notes of classroom activities and teacher interviews and used to evaluate the science lessons. The researchers' opinion of the likelihood of the lesson to enhance student understanding was used to rate the quality of the lessons. Data from actual student learning was not included. However, examples of the lessons were given and the ratings were based on the students' engagement in meaningful science concepts. Due to the variety of lessons that met this objective, the authors suggest "the key [to science education] is not the particular instructional strategies that are used, but rather engaging students in ways that lead to their conceptual understanding."

From Pasley et al.'s (2004) analysis of the lessons, several factors of effective instruction emerged. These included engaging students with science content, creating a conducive learning environment, ensuring access for all students, using questioning to monitor and promote understanding, and helping students to make sense of the science content. The researchers suggested how science is portrayed may underlie many of these factors. To gain student interest, the researchers suggest using interesting questions and real life context, sharing the goal of the lesson with the students, first hand experiences, stories and games. It was also suggested that students should see science as an investigative process rather than a static body of knowledge. Only 21% of the observed lessons met this criterion. Half of the lessons were rated as developmentally appropriate, however of those that were not, many were at a lower level most of the students could engage in. Multiple representations of concepts helped to facilitate learning for students of a variety of prior experiences and knowledge. This created a conducive learning environment, which was both rigorous and respectful. Only 14% of science lessons nationally provided intellectual rigor including constructive criticism, and challenging ideas.

Pasley et al. (2004) found once students were focused on important science content (65% Nationally did this), and engaged in an appropriate, accessible learning environment, the teacher's effectiveness in asking questions, providing explanations, and pushing student thinking forward determined students' opportunity to learn. Nationally, 16% of the lessons effectively used questioning to push student thinking forward by both assessing students current understanding and provoking meaningful thinking in helping students to make sense of the science concepts. Only 13% of the lessons accomplished adequate sense making through questioning or other means. Sorting out the big ideas from the supporting ones, and making connections between the concepts and the lab activities were often left up to the students.

Based on their findings, Pasley et al. (2004) suggest ongoing professional development that focuses on elements of effective instruction rather than particular instructional strategies. The researchers were looking for specific elements and there may be more factors involved than those studied here. The study did highlight many areas in which the US could improve science instruction and their suggestions are founded on a large body of research. The suggestion of professional development based on best practices rather than a one-size-fits-all instructional strategy is appropriate based on their findings.

Learning Preferences and Goals, and Instruction

Tsai (2000) examined the possible relationships between student Scientific Epistemological Beliefs (SEB) and perceptions of constructivist learning environments, with applications for the improvement of science teaching and learning. Patrick and Yoon

(2004) found high mastery and low performance goals were associated with the largest gains in understanding. Heyworth (1999) found teachers, being experts and familiar with a problem, might tend to use a working forwards approach when demonstrating how to solve a problem. But for students, when a problem is unfamiliar, mean-ends analysis is the strategy to be employed initially. During talk-aloud sessions, teachers can help students to focus on the goal of a problem then to set up appropriate sub-goals in order to create a qualitative procedure. In She's (2005) study, the potential to promote students' understanding of difficult science concepts through an examination of the interrelationships among the teachers' instructional approach, students' learning preference styles, and their levels of learning process was explored.

Tsai (2000), through analyzing 1,176 tenth grade students' questionnaire responses from fourteen high schools, attempted to examine the possible relationships between student Scientific Epistemological Beliefs (SEB) and perceptions of constructivist learning environments, with applications for the improvement of science teaching and learning. The schools selected included six high schools in Northern Taiwan, and four high schools from each Central and Southern Taiwan. and 47 percent of them are females. For each selected school, two classes were chosen. The selected Taiwanese tenth-graders had various academic backgrounds, demographic areas and socio-economic levels, and were roughly representative of the Taiwanese tenth-grade population.

Tsai's (2000) study used 16 items from a Chinese version of Pomeroy's questionnaire items that represent a continuum from empiricist views to constructivist views to one dimensionally assess students' SEB. The questionnaire consists of bipolar agree/disagree statements on a 5–1 Likert scale. The empiricist view describes scientific knowledge as the discovery of an objective reality external to us that is discovered by observation experimentation, or application of a universal scientific method. The empiricist position may also claim that evidence in science that is accumulated carefully will produce infallible knowledge. On the other hand, the constructivist views of science highlight the theory-laden quality of scientific exploration and the role of conceptual change in the progression of scientific understanding. These views also support an idea that scientific knowledge should be viewed as an invented reality, that is constructed through the use of agreed upon paradigms, accepted forms of evidence, social negotiations, as well as cultural and contextual impacts as recognized by practicing scientists.

To assess students' perceptions of constructivist learning environments, Tsai (2000) administered a Chinese version of the *Constructivist Learning Environment Survey* (CLES). The CLES assessed the extent of agreement between actual learning environments and constructivist learning environments, as well as the match between students' views about ideal learning environments and constructivist ones.

Tsai (2000) claimed the results revealed that there were some relationships between students' scientific epistemological beliefs and their perceptions of constructivist learning environments. Constructivist-oriented SEB students did not tend to prefer student-centered learning activities more than did those who held empiricist views of science. Many of them, whether they were categorized as constructivist- or empiricist-oriented SEB learners, still tended to rely on teachers' authority for lesson planning. Furthermore, there were negative relationships between student SEB orientations and perceptions of actual learning environments. Students having SEB more orientated to constructivist views of science tended to perceive that actual learning environments did not offer adequate opportunities for them to either negotiate their ideas ($r = –0.09$, $p < 0.01$), or integrate with their prior knowledge ($r = –0.08$, $p < 0.01$). Moreover, students holding epistemological beliefs close to constructivist views about science tended to show significantly stronger preferences to learn in the constructivist environments, where they could interact, negotiate meanings and build consensus with others ($r = 0.22$, $p < 0.001$); have enough time to integrate their prior knowledge and experiences with newly constructed knowledge ($r = 0.20$, $p < 0.001$); and have opportunities to exercise deliberate and meaningful control over their learning activities and to think independently ($r = 0.17$, $p < 0.001$).

Tsai's (2000) findings may suggest that compared to constructivist–aligned students, empiricist-aligned SEB students may have perceptions more closely matched with actual and preferred learning environments. However, constructivist-oriented SEB students may express a remarkable discrepancy towards these two sets of learning environments. Results from the study showed there was no significant correlation between students' epistemological beliefs about science and the extent of their preferences to experience learning as a process of creating and resolving personally problematic experiences. However, students with epistemological beliefs tending towards a more constructivist view of science tended also to prefer constructivist-oriented learning environments.

Tsai (2000) believed the interaction between student SEB and learning environment perceptions indicated that students who express a philosophical perspective closer to a constructivist view of science might benefit most from constructivist science teaching. It further implies that an appropriate view about a constructivist epistemology of science may be an essential prerequisite for implementing constructivist-based instructional strategies.

Tsai (2000) claimed constructivist SEB students might have difficulty learning in common science classrooms due to the discrepancy of perceptions expressed by these students. Because of this, Tsai suggested teachers need to be highly aware of students' epistemological orientation towards science, should accommodate these preferences when designing learning experiences, and teachers should especially provide constructivist-based lessons to enhance science learning for students who are epistemologically constructivist-oriented.

This study was not conducted with an experimental research design in place; hence, it is limited to correlation analyses between students' scientific epistemological beliefs and learning perceptions. However, this research strongly suggests that student scientific epistemological beliefs were an essential component in determining students' learning perceptions or orientations. This study did not compare the learning outcomes of students with a constructivist aligned SEB students with empiricist aligned SEB students. However, based on research previously cited in this chapter, constructivist learning environments may have a positive effect on the development of conceptual understanding. Rather than accommodating empiricist aligned SEB students with non-constructivist lessons, perhaps lessons could focus on helping those students become more constructivist aligned. This approach may add to the success of both constructivist aligned lessons and the development of conceptual understandings.

Patrick and Yoon (2004) chose four motivated eighth-grade students from a

Chicago school to qualitatively examine combinations of students' beliefs and the nature of their conceptual understanding and changes in that understanding. Quality as opposed to level of motivation during an inquiry-based *Global Warming* project based curriculum was the focus of the study. Students were videotaped and completed a pre-test and post-test of comparable items at the beginning and end of each unit respectively during the six-week study duration. The test consisted of multiple choice and short answer question that emphasized conceptual understanding rather than factual recall.

Two of the four participants in Patrick and Yoon's (2004) study showed significant gain from the pre-test to post-test ($p < .0001$) and three of the four showed a gain. Of the three students, all were mastery oriented. The highest achiever on the post-test was most interested in appearing smart in front of his peers and his mastery orientation was somewhat unclear and possibly obstructed by this desire. The lowest achiever, whose pre-test and post-test scores were equivalent, also exhibited a strong performance approach; however, in addition this student showed a very low mastery-goal orientation. The student who saw the largest gain was claimed to be highly mastery oriented, as indicated by her thoughtful statements and desire for meaningful learning. The second student, whose gains were just under the class average, switched back and forth from a desire to attain a conceptual understanding to that of a factual one. This student was also highly concerned with her peers' perceptions of her.

In addition to having a mastery orientation benefiting conceptual understanding, Patrick and Yoon (2004) also believed the results show a high performance orientation may interfere with understanding and conceptual revision. In this case, they found high mastery and low performance goals were associated with the largest gains in understanding. The authors acknowledged the small sample size limits the generalizability of the findings. However, they claimed these results are supported by other research and they advocate that teachers strive to foster high mastery orientation and decrease the emphasis on performance goals. This can be particularly true for adolescents who are self-conscious and who would benefit most from a positive learning community.

Chemistry and physics often require the integration of math concepts including volumetric analysis. Heyworth (1999) categorized students from two, 12th year classes into either experts or novices depending upon their conceptual understanding as measured by a problem-solving test at the completion of a unit on volumetric analysis. Twelve students were selected at random; these included six “experts” and six “novices”.

Heyworth (1999) collected data on the students' procedural and conceptual knowledge through an audiotaped and transcribed, interview process. This process included a think aloud interview, in which students were instructed to talk out loud while solving problems or answering questions. After students had indicated that a task had been completed, the interviewer asked probing questions. All interviews were conducted in English, the students' second language, (English is used as the medium of instruction at the school, and no language-related difficulties were evident in either oral or written communication). From the interviews, inferences were made about the students’ procedural and conceptual knowledge. Whenever inferences could not fully account for students’ responses, further questioning based on these inferences was carried out in later sessions and the inferences refined. The same teacher, who introduced concepts and formulas in a way that emphasized definitions and mathematical formulas, had taught both classes.

Heyworth (1999) claimed qualitative research shows that problem solvers have a variety of strategies available. The one actually employed depended on the familiarity of the problem and whether students switched to strategies that were more efficient or more likely to lead to a solution. The expert students in the study demonstrated fully integrated conceptual knowledge of the two formulas needed to accurately solve the problem. This was demonstrated by their ability to identify and link together the key concepts to create a general qualitative procedure. The use of key words formed a significant part of the initial problem representation, which for experts, lead to a qualitative procedure of a problem. Formulas were referred to in order to abstract the major entities needed for the procedure. The details were only worked out when the final mathematical solution to the problem was obtained. On the other hand, novices, had misconceptions or a hazy understanding for the key concepts and this resulted in a variety of erroneous formulas. Sometimes formulas were memorized and applied algorithmically.

Heyworth (1999) suggested that to encourage identification of key words and qualitative thinking, teachers could allow students to talk aloud while solving a problem. This would include talking about the key words in problems and the derivation of qualitative, non-mathematical procedures. Oral discussions could be carried out either at the chalkboard or by getting students to work together in small groups or pairs, with instructions to derive general procedures rather than mathematical solutions. Talking aloud would also help teachers and students to identify misconceptions or reveal areas of knowledge not clearly understood, but which were nonetheless needed to solve problems.

Teachers, being experts and familiar with a problem, may tend to use a working forwards approach when demonstrating how to solve a problem. But for students, when a problem is unfamiliar, Heyworth (1999) argued mean-ends analysis is the strategy to be employed initially. During talk-aloud sessions, teachers can help students to focus on the goal of a problem then to set up appropriate sub-goals in order to create a qualitative procedure. Initial problem solving will be slow. As the solution path becomes familiar, students should switch to the more efficient working forwards strategy used by experts.

In addition, Heyworth (1999) believed once students have derived and understood procedures for problems, they should be given plenty of practice to master the procedures and to encode them in long-term memory. Too often, teachers move on to new topics before slower students get sufficient practice to do this. Once encoded, procedures can be readily accessed from long-term memory and used almost automatically as is done by experts. This could be beneficial when solving longer, more complex problems that contain basic procedures as components of the overall solution.

The use of just two classes precludes true random sampling. Due to time requirements, only a small number of students could be interviewed. Thus, care is needed before generalizing the findings to the whole population of problem solvers for this topic. In addition, triangulation was not used as a method of ensuring internal validity of the study.

In She's (2005) study, the potential to promote students' understanding of difficult science concepts through an examination of the interrelationships among the teachers' instructional approach, students' learning preference styles, and their levels of learning process was explored. This study involved 462 Grade 8 students from 16 classes in 4 schools, consisting of 232 male and 230 female students. All of the students were about average in their grade level on the basis of their school assessment. The independent variables of the study included the four different instructional approaches, four different learning preference styles, and three different levels of learning process; the dependent variables were immediate posttest and retention test scores of air pressure.

Four different classifications for learning preference styles, based on brain physiology, were used in She's (2005) study. The four quadrants of the brain are labeled A, B, C, and D counterclockwise beginning with the left cerebral quadrant: Quadrant A (QA, the upper left cerebral quadrant, external learning) Quadrant B (QB, the lower limbic left quadrant, procedural learning) Quadrant C (QC, the lower limbic right quadrant, interactive learning) Quadrant D (QD, the upper right cerebral quadrant, internal learning). The following is a more detailed description of these learners: QA is logical, factual, analytical, technical, mathematical, and critical. These learners prefer to be taught from authority through lectures and textbooks. They do well in the traditional, lecture-based, textbook-driven classroom and look to teachers to provide knowledge in answering questions. QB is sequential, structured, organized, planned, and detailed. These learners prefer to learn through a methodical, step-by-step testing of what is being taught, as well as practice and repetition to improve skills. They do well in the hands-on activities and use abstract knowledge and common sense. QC is interpersonal, kinesthetic, emotional, sensory, and feeling. These learners prefer to learn through experience, feedback, listening, experiencing sensory input, and sharing ideas. And QD is visual, holistic, innovative, imaginative, and conceptual. These learners prefer to learn through visualization, insight, idea synthesis, and sudden understanding of a concept holistically and intuitively.

She's (2005) study is a three-factorial quasi-experimental design investigating the effects of the four different instructional approaches, four different learning preference styles (QA, QB, QC, and QD learning preference styles), and three different levels of learning process (rote learners, in-between learners, and meaningful learners) on students' immediate performance and retention of air pressure concepts. The learning preference questionnaire (LPQ) and inventory of learning processes (ILP) were both found to be reliable, and the pre and posttests were found to be moderately reliable.

The classroom teachers administered the LPQ, two scales of the ILP, and the pretest of air pressure of She's (2005) study to 462 Grade 8 students before they had learned the air pressure concepts. Students were given the posttest of these concepts immediately after the instruction and then were given a retention test 3 months after the instruction.

She's (2005) randomly assigned participants to four instructional treatment groups: QA-oriented instructional group (4 classes, n = 112), QB-oriented instruction group (4 classes, n = 119), QC-oriented instruction group (4 classes, n = 109), and QD-oriented instruction group (4 classes, n = 122). The assignment of a class into QA-, QB-, QC-, or QD-oriented instruction treatment was random. No significant differences among the results of the QA-, QB-, QC-, and QD-oriented instructional groups' students on the pretest ($F(3, 458) = 0.86$).

She's (2005) ensured the content and objectives of the QA-, QB-, QC-, QD-oriented instructions were the same, and all of the content covered in this study was based on the current physical science textbook. The concepts related to air pressure included in this study were (a) the existence of air pressure, (b) air exerts pressure, (c) the strength of air pressure, (d) measuring air pressure, (e) air can be compressed, and (f) air exerts pressure in all directions. However, the method of presenting QA-, QB-, QC-, QD-oriented individual science lessons varied according to each student's QA, QB, QC, or QD style of learning preference.

In She's (2005), students in the QA-oriented instructional group learned these concepts by conventional methods. The teachers who taught in this group primarily used the booklet to help students construct the concepts in a traditional way and then asked students to solve problems relevant to what they had learned from the textbook. The teachers also provided students with opportunities for questions and answers. Students in the QB-oriented instructional group learned these concepts by doing experiments. Teachers then asked students to solve problems relevant to their experiments. The teachers also helped students connect the results of each experiment to construct concepts involving air pressure. Students in the QC-oriented instructional group learned the concepts by watching an interactive flash cartoon in which two characters discuss concepts about air pressure. Teachers who taught in the QC-oriented instructional group discussed concepts with students after each section of the interactive flash cartoon and then asked students to solve problems relevant to the content presented by the cartoon. Students in the QD-oriented instructional group learned these concepts by watching a video compact disk (VCD) of an actual experiment in which a teacher demonstrated each experiment, beginning with questions to make the students think, and then provided explanations for why a result occurred. Teachers who taught in the QD-oriented instructional group asked students to solve problems relevant to the experiment demonstration (VCD) and provided students with opportunities to discuss or ask questions.

She's (2005) results indicated a significant effect for the three levels of learning process on both the posttest scores, $F(2, 459) = 7.71$, $p = .001$, and retention test scores, $F(2, 459) = 11.44$, $p = .000$. Thus, the three levels of learning process significantly affected students' posttest and retention test scores. A post hoc analysis for main effect suggested that the meaningful learners performed significantly better than in-between and rote learners (meaningful learner > in-between learner, *p*(post) = .000, *p*(retention) = .000; meaningful learner > rote learner, *p*(post) = .007, *p*(retention) = .000) on the posttest and retention test.

The pattern of She's (2005) posttest and retention test scores for meaningful learners, in-between learners, and rote learners after receiving four types of instruction indicates that meaningful learners performed better on the posttest when they received QB instruction than when they received any other types of instruction. Significantly, meaningful learners retained more than the other students, regardless of the type of instruction. Rote learners performed better on both the post- and retention tests when they received QD instruction rather than any other types of instruction.

She (2005) believed this result sheds light that rote learners have more successful learning when using QD instruction that provides opportunities to actively involve thinking and visualizing real events. It implied that QD instruction helps rote learners learn invisible, abstract, and process concepts more successfully. It also implied that rote learners' learning style should be considered more carefully because they are affected more by the type of instruction.

She (2005) observed students who are meaningful learners and also have QB learning preference styles performed best on both the posttest and retention test. In addition, students who are rote learners and have QA learning preference styles performed best on both the posttest and retention test. In-between learners with QD learning preference styles performed better on the posttest. Students with the QB learning preference style performed better on the posttest after receiving QB instruction. Students with the QA learning preference style performed better on the posttest after receiving QD instruction. Students with the QD learning preference style performed better on the posttest after receiving QC instruction. Students with the QB, QC, and QD learning preference styles performed better on the retention test after receiving QD instruction. The results of this study do not show that matching students' learning preference styles with their teachers' instructional style does result in better immediate understanding or retention of air pressure concepts.

This study further demonstrates that meaningful learners retain more than other types of learners, even though the method of instruction was not meaningful-oriented. This may be because meaningful learners learn in their own way and develop better retention no matter what type of instruction they receive, implying that meaningful learners are able to adapt to any type of instruction.

These findings imply that the students' levels of learning process are important in determining how effectively students can construct knowledge and retain knowledge. Moreover, meaningful learners performed significantly better than in-between learners and rote learners on both the posttest and retention test. The author argues learning in a meaningful way is the key for leading students to successful learning; thus, giving students the opportunity to learn in a meaningful way should be the first priority of teaching.

This large-scale study attempted to find connections between several factors including learning process level, learning preference, and instructional strategy. Through random sampling, thorough analysis and a large sample size, this study credibly supports

Ausubel's claim that meaningful learning comes from the ability to construct and retain knowledge. However, this study suggests the type of instruction has less of an affect on this ability than students' level of learning process. This study raises the question of how do students become meaningful learners?

Summary

The literature reviewed here emphasizes the importance of teachers reflecting on their practice in relation to student learning. The studies showed the student learning gains when teachers can effectively adjust their teaching methods to meet the needs of the students and encourage the students to strive for conceptual understanding. Conceptual understanding cannot be simply transmitted form teacher to student through passive learning. The student must take an active role in learning with the careful guidance of a well-informed teacher.

The teacher's role begins with assessing students' prior knowledge through pre-assessments. Once the students' prior knowledge is assessed, the teacher can design instruction that will help students make connections between the new information and their current understandings. These connections need to be explicit and may also need to require the student to experience cognitive conflict. Cognitive conflict helps the student to see discrepancies between everyday knowledge and scientific explanations.

Students' prior conceptions are tenacious and the students must actively do the restructuring of them. When students understand the nature of science to be about investigating and evaluating current scientific understandings, students may be more open to investigating and evaluating their own understandings. The student must also want to actively participate in the learning process. Motivation and learning goals play an integral role in active learning. Taking on such an active role in learning also requires metacognition, which helps the student monitor their learning, so they can see how their understanding has changed over time and seek further improvements. Students need a significant amount of support in this process.

All students can meet high expectations, which are developmentally appropriate, when effective teaching practices that promote active learning are used to support the development of conceptual understandings. The following chapter will summarize the research, evaluate how the current research relates to the historical framework, examine the resulting classroom implications more specifically and suggest areas for future research.

CHAPTER 4: CONCLUSION

Clearly science education in the United States has come a long way in the last one hundred and fifty years. The need for a clear understanding of scientific concepts and theories has become increasingly important with the population growth, global economy, prevalence of computers in most occupations, and growing environmental concerns. No longer is science education just a good way to exercise the mind. The future prosperity and quality of life relies on quality science education for all students.

The current educational research has built on ideas from the past of Dewey, Piaget, Vygotsky, and Ausubel to create a more complete picture of student learning and cognition. The idea that meaningful knowledge is constructed from experience and interactions with the natural world and other members of society is an important foundation.

Summary of Findings

Educators know there is much more to teaching and learning for conceptual understanding than simply having pertinent experiences and sharing them. The experiences must be developmentally appropriate and logically ordered for students to make sense of them. Curriculum should be centered around broad concepts, worth investigating, so students may understand how scientific concepts are related. However, curriculum alone does not provide teachers the information they need to make learning a successful experience for all students. Factors including prior knowledge, cognitive conflict, group collaboration, students' ideas and explanations, the nature of science (NOS), motivation, metacognition, and learning preferences, goals and instructional techniques also play an integral role in the success of any curriculum. The following is a summary of the findings in these areas from the research critically reviewed in the previous chapter.

Prior Knowledge

The findings from several studies including Cavalcante and Newton (1997), Cavallo (2003), Dalton et al. (1997), and Park and Kim (1998) supported Ausubel's (2000) claim that students' prior knowledge is the most important information for an educator to be knowledgeable of prior to teaching a topic or concept. Researchers have elicited this knowledge through discussion (Asoko, 2002; Bell, 2005; Coll & France, 2005; Geelan et al., 2004; Hammer & Elby, 2003; Pugh, 2002; Swafford & Bryan, 2000; Tao, 2001; vanZee & Minstrell, 1997; Yip, 2004) or in written form (Cavallo, 2003; Fellows, 1994).

Ausubel (2000) also argued the primary way of adding information to one's cognitive structure is to link new ideas and details in a subordinate fashion to the anchoring concepts already present from prior knowledge. Novak (Wandersee et al., 1994), who built on Ausubel's theories, believed students' prior misconceptions anchor new related learning and often new information causes the misconception to be elaborated or convoluted to accommodate the new information rather than to overwrite it. Cavallo's (2003) attempt to examine this assertion indicated researchers and educators need to consider the purpose and potential of application activities' ability to promote student understanding and to be aware that students construct an understanding of the concept during initial experiences with the concept. Thus, educators should carefully implement instruction, activities, and vocabulary introduction to guide students toward what may be the first and only construction of a particular concept.

Several other researchers (Cavalcante & Newton, 1997; Dalton et al., 1997; McElwee, 1991; Park & Kim, 1998; Vosniadou, 2001) have also examined the connection between students' prior knowledge, and conceptual understanding. Cavalcante and Newton (1997), Dalton et al. (1997), and Park and Kim (1998), analyzed how prior knowledge of students' conceptions affect learning when an inquiry method of instruction is used.

Cavalcante and Newton (1997) found conceptual understanding was best served by the lessons that provided a conceptual structure at the outset. A practical investigation followed by a safety net of relevant textual information produced generally lower gains in conceptual understanding than those produced by the other lesson forms. They hypothesized when a learner has a low level of conceptual knowledge and understanding to start with, then providing a conceptual structure may be particularly beneficial. As the initial level of conceptual knowledge and understanding increases, the value of providing a conceptual structure may decline. At higher levels of initial conceptual knowledge and understanding, the advantage may move to lessons that withhold conceptual structures.

Park and Kim (1998) compared students' responses to experimental evidence obtained through simple observations and those obtained from controlling variables to determine how students' responses to experimental results differ when the evidence results from varying levels of inquiry skills. The results indicated observations made from controlling variables increased cognitive demand, which in turn increased understanding. This supports the idea that learners must challenge the information they are presented with and intentionally try to make sense of it through negotiations with their prior knowledge.

Dalton et al. (1997) examined the differences in impact on fourth grade students' conceptual learning from a supported inquiry science (SIS) unit versus an activity based science (ABS) hands-on electricity unit. The SIS unit required students to experiment with their own designs and hypotheses and to debate these ideas with their classmates. The results indicated hands-on science is an important component of effective science instruction for all students, but must be structured in a way that focuses on students' evolving alternative conceptions as the SIS unit did, rather than procedures and outcomes as in the ABS unit. The SIS principles also included many opportunities for students to co-construct meaning with their partners and classmates via recursive experience-based discussions, all the while guided by the teacher-coach who was knowledgeable about likely misconceptions and underlying concepts.

An important aspect of current educational research explores epistemological aspects of learning (Pintrich & Sinatra, 2003). How are student beliefs an asset or hindrance? What drives student motivation? What effect can teachers have on student beliefs and motivation in the fifty minutes each class period provides? The answers to these questions are becoming clearer. As the aforementioned research has established, each student is different and comes to school with an individual framework of past experiences from which the teacher builds upon and shapes to enhance learning.

Conceptual Change and Cognitive Conflict

Once students' prior knowledge, conceptions, and misconceptions are established, cognitive conflict (Chi et al. 1994; Jonassen et al., 2005; Niaz, 2002; Park and Han, 2002) has been used to guide students to scientific understandings. McElwee (1991) and Vosniadou (2001) intentionally incorporated information about students' prior conceptions to initiate cognitive conflict and promote conceptual change.

McElwee (1991) explored the personal ideas held by a group of students to examine the changes that take place in conceptual knowledge immediately after instruction using a strategy of conceptual conflict resolved through the mediation of analogy. The results indicated that for a few of the students the analogy was sufficient to aid their transition from personal to scientific understanding. However, the majority did not adequately benefit and either compartmentalized their new knowledge or failed to change their personal concepts to scientific concepts. This study does highlight the need for teachers to be selective with the analogies they use in order to help students mold their personal understandings into scientific ones without reinforcing common misconceptions.

Vosniadou et al. (2001) wanted to determine whether the students had developed an explanatory framework that incorporated multiple concepts. The study incorporated research on the acquisition of science concepts into the construction of an experimental learning environment. The experimental learning environment included students working in small groups, beginning class with a question, followed by a small group discussion, and in-class experiments to provide an objective answer when conflict arose. In addition to these activities, student prior knowledge, the use of models, symbolic representations, measurements, and cognitive conflict, carefully ordered concept introduction, and distinction between the scientific and common meanings of terms were also implemented.

Students' successes in the experimental learning environment were attributed to questioning methods resulting in complex student explanations, which allowed student beliefs and conceptions to be negotiated among the class members. This study successfully incorporated several changes based on research into the learning environment to promote conceptual change. However, the research does not determine whether one particular change, such as incorporating students' prior knowledge, or a combination of changes contributed to the gains in the experimental group. The environment appeared to be a fertile ground for cognitive conflict, but more importantly also nurtured resolution of this conflict. The findings from this study support the need for teachers to create learning environments with a variety of instructional strategies based on student prior knowledge, where students feel safe to negotiate their current beliefs with new information.

Conceptual Change and Group Collaboration

In addition to Dalton et al (1997), McElwee (1991), and Vosniadou (2001), numerous others (Basili & Sanfdord, 1991; DeVries et al., 2002; Nakhleh, 1996; Niaz, 2002; Tao, 2001; Tao & Gunstone, 1999) have also studied conceptual change learning in relation to specific instructional strategies. Niaz (2002) studied how generating situations and experiences in which students were forced to grapple with, and reconcile, alternative responses in a group setting so all students may benefit from the cognitive conflict of others. This study found these teaching experiments needed to be tailored to the specifics of a problem situation in order to facilitate conceptual change. Tao and Gunstone (1999) also incorporated a collaborative learning strategy to elicit cognitive conflict and promote conceptual change. This research shows that social construction of knowledge took place during peer collaboration and in many cases this led to students' conceptual change in the context of the tasks attended to. However, when probed at a later time, many students had regressed to alternative conceptions. When the co-construction of knowledge was accompanied by personal construction, conceptual change became stable over time. Students who took initiative to intentionally reconstruct their knowledge showed the most lasting change. In general, this study illuminated the need for research into motivation and conceptual change. This connection was later supported in literature reviews by Andre and Windschitl, 2003; diSessa et al., 2003; Hynd, 2003; Linnenbrink and Pintrich, 2003; Mason, 2003; and Southerland and Sinatra, 2003.

Basili and Sanford (1991) included small group cooperative tasks to elicit misconceptions, which could then be discussed in contrast to the scientific conceptions that had been taught through direct instruction. Although they found the treatment groups to have a significantly lower proportion of misconceptions, these findings are suspect due to the ambiguity of how the treatment students were chosen, and the incentives to perform well on the exam that were not provided to the control group. In addition, it could be argued that the demonstrations provided actually decreased the amount of pertinent instruction the control group received, since the demonstrations were not associated with the target concepts the students were tested on. Also, the coding system used to evaluate both verbal behavior and group dynamics was highly inferential and not supported by any other evidence. This study had several flaws and the findings were not corroborated with the other literature reviewed here.

Nakhleh (1996) incorporated groups of six-nine students who worked on common problems and then presented the proposed solutions to the other groups. Although the results showed improved student learning, several professional assistants were infused into the classroom and the research did not examine the effect of the smaller student-teacher ratio, as opposed to instructional methods on student performance. Tao (2001) facilitated students confronting varying views while working in small groups to solve qualitative physics problems. The results show that confronting students with varying views have positive effects on students' learning from pre- to post-test. However, student motivation may have played an important role. De Vries et al. (2002) studied how the design of a computer mediated CONNECT program facilitated co-construction of knowledge. The results indicated technological intervention help mediate social pressures, which may have an affect on students' ability to collaboratively and constructively confront opposing ideas in peer groups. In addition, this study, like Tao and Gunstone (1999) and Tao (2001) reinforced the need for students to be motivated in order for them to examine and construct understandings.

These studies indicate when students confront and mediate their prior knowledge within group settings, student learning improves if the environment motivates students within a safe context to make these reconciliations. One way to achieve this goal is to elicit and explore students' ideas and explanations.

Conceptual Change and Students' Ideas and Explanations

Fellows (1994) asked students to explain their ideas both orally and in writing to increase their metacognitive awareness and compare their ideas with other students' ideas. The study found students demonstrated conceptual change by adding new principles to their existing schema and/or reorganizing their schema to better align with scientific explanations. The research also found more than half of the students attained the intended goal concepts when the lesson offered students more focused and balanced opportunities to practice expressing their ideas in written and oral form. Less than half of the students attained the intended goal concepts when these instructional practices were not in place. The researchers claim that students' expression of their ideas in written and oral form enhanced learning was supported by their careful research. However, this was accompanied by careful observations and instructional strategies based on these observations. The latter is likely required for the former to be effective.

VanZee and Minstrell (1997) used ethnographic methods with a case study to qualitatively analyze how teacher questioning, in the form of the "reflective toss", can assist students by helping them "to make their meanings clear, to consider points of view in a neutral manner, and to monitor the discussion and their own thinking." Minstrell's reflective toss method emphasized students' ideas, engagement in meaningful discussions, and creation of a culture of respect for student ideas.

Edens and Potter (2003) examined the use of drawings as an instructional tool to promote conceptual change. They concluded pictorial representation provides a viable way for students to learn scientific concepts by helping them to construct mental models on which the learner can make inferences. However, the researchers failed to control for several variables, including increased scaffolding provided to the experimental group and the affect of communicating through writing alone. Unfortunately, since no further research on the power of illustrations in enhancing student learning was uncovered in the review of the research presented here these findings could neither be refuted nor corroborated.

The results of Park and Han's (2002) study indicated deductive reasoning might be required for students to experience conceptual change. The idea that students must understand the premises to an argument before it will be plausible to them is not surprising and may be quite generalizable. However, the results from this study are only applicable to Newtonian physics. In addition, with a small sample size from outside of the US such generalizations may not transfer.

These studies built upon students' prior knowledge through careful observations during the solicitation of student ideas. When students' ideas were carefully elicited and used to guide further instruction, student learning was improved. However, many studies (deVries et al., 2002; Lederman and Lederman, 2004; Lin et. al, 2004; Solomon et al., 1992; Tao, 2001; Tao and Gunstone, 1999) have found students' view of the nature of science (NOS) and motivation may influence their ability to integrate knowledge in a meaningful way.

Conceptual Change and the NOS

Many researchers (Solomon et al., 1992; Lederman and Lederman, 2004; Lin et al., 2004) have also argued that in order for any instructional strategy aimed at promoting conceptual change to be effective, students must believe scientific theories are ideas and explanations, rather than facts set in stone. Solomon et al. (1992) found when the history of science is incorporated into instruction to help students better understand the nature of science and promote conceptual change learning, students demonstrated a significant shift in seeing the purpose of experiment as making a discovery, to a trying out explanations. These shifts in students perceptions were attributed to studying theories in the controversial context from which they arose, helping students to focus on the reasons for accepting or rejecting a theory, and presenting the historical perspective making conceptual change easier for students to accommodate. However, much of the improvement may have stemmed from the extra help available, new learning materials, and innovation enthusiasm on the part of the authors (Hawthorne effect).

Lin et al. (2004) studied students' problem solving ability and found student beliefs about the NOS was the best predictor of this ability. In addition, the researchers found the problem solving strategies of the students who scored highly on the nature of science survey were also more conceptually based. Despite the fact that the follow-up interviews were limited to four students solving only two test items, this study provided both quantitative and qualitative evidence that students' understanding about the NOS is strongly related to their problem-solving strategies. This result lends support to the argument by the American Association for the Advancement of Science (1991) that promoting students' understanding of the NOS is important because better understanding of the NOS might result in higher conceptual problem-solving ability. However, this correlational study cannot assert a direct relationship between NOS and higher conceptual problem-solving ability.

Although the mechanism of how and why thorough understanding of NOS results in better achievement in conceptual problem solving needs to be scrutinized. This difference can be partly explained by the findings of Songer and Linn (1991) and Hart et al. (2000). In Songer and Linn's (1991) study, it was found that the students who view science as static assert that science consists of a group of facts that are best memorized.

On the other hand, those who view science as dynamic believe that scientific ideas develop and change, and that the best way to learn these ideas is to understand what they mean and how they are related.

Hart et al. (2000) switched the purpose of lab experiment from getting results to further content knowledge, to conducting experiments to investigate and communicate results, then examined student understanding of the NOS. The researchers found students to better understand the nature of science and how scientific facts are established, including the fallibility, passion, commitment, and creativity involved in scientific work, and experience the role of the scientist. The conceptual understanding students gleaned in terms of content knowledge was not measured or discussed. However this study did portray a science classroom in which students (all girls) were, in Dewey's terms, wholeheartedly experiencing genuine science. This experience was not without significant difficulty in terms of safety, time, organization, set-up, and teacher support needed to make this a successful experience.

The students' experience lasted six weeks (one unit); it would be most interesting to see if the experience had any affect on students' learning in future classes. Would students be more likely to engage in meaningful learning? Other research (Lin et al., 2004; Pugh, 2002; Solomon et al., 1992; Songer & Lin, 1991; and Tsai, 2000) has suggested when students view the nature of science as dynamic and evolving, students will choose to learn in more meaningful ways, thus more likely to achieve conceptual understanding.

Songer and Linn (1991) characterized students' beliefs about the nature of science to assess the relationship between these beliefs and students' propensity to integrate knowledge of thermodynamics. The results showed students are likely to gain a more integrated understanding of science if their courses offer students a range of loci and emphasize both knowledge integration and knowledge about the nature of science. They suggest this must be done with instructional interventions specifically focusing on integration, rather than isolated scientific ideas. These suggestions are well founded based on the results of their careful research and analysis. However, student beliefs may be an effect of their knowledge integration skills rather than a precursor to this ability. Either way, this study shows learning is enhanced when students are encouraged to integrate knowledge into a dynamic belief system.

In contrast, McCleary and Tindal (1999) used explicit, rule-based, concept anchored instruction and small steps to construct students' knowledge of the scientific method. In general, the researchers found the experimental group to perform significantly better than the control group on nearly all areas measured. In addition to major research over sites, the results could simply reflect the reduction in class size. Construction of knowledge does require instruction; it is unlikely to occur without careful guidance. The structure of this instruction, and the extent to which it needs to be explicitly taught under rigid rules and guidelines, is still up for debate.

These studies strongly suggest students who view science as an interconnected, evolving body of experimentally supported evidence are more apt to make connections between theories, evidence and prior knowledge than those who view science as static, isolated facts. However, in addition to viewing science as more than isolated facts, studies (deVries et al., 2002; Tao & Gunstone, 1999; Tao, 2001; Zusho & Pintrich, 2003) have indicated students must also have the motivation to integrate knowledge in a meaningful manner.

Conceptual Change and Motivation

Zusho and Pintrich (2003) investigated the role of certain motivational components and their relation to students' learning and achievement outcomes in two college chemistry courses. Taken together, the authors suggested these findings show that it would indeed be remiss to ignore issues related to students' motivation and affect in the study of students' science learning. As Pintrich et al. (1993) state, it is not enough to examine issues related to students' 'cold' conceptual change. Educators must also consider how students' motivational processes such as self-efficacy and task value influence the learning process. There are several implications of this study. First, it is important to facilitate adaptive motivational beliefs. For example, one can help maintain self-efficacy levels by communicating the role of effort and strategies. In other words, it is essential for instructors to convey to students that chemistry is indeed learnable, and that one can increase one's knowledge and skill of chemistry by employing specific strategies. It is also vital for chemistry instructors to focus on task value in their pedagogy and explanations of course material, as well as relate instruction and assessment to the relevance and utility of chemistry for everyday life. Second, it is important to facilitate strategy use. Instructors might consider modeling specific strategies or ways of thinking for learning chemistry in class, in addition to encouraging students to share their own strategies for learning the course content.

The population of this study was mainly Caucasian college students. It would be interesting to investigate these questions with a younger and/or more diverse population.

The results of this study were carefully analyzed and supported by other research. Zusho and Pintrich's (2003) suggestions could be generalizable to similar populations and further research based on their findings could shed light onto why college chemistry classes are often mostly Caucasian.

Once students are sufficiently motivated to incorporate dynamic and integrated science knowledge with their prior knowledge, employing metacognitive processes stabilizes this knowledge (Case & Gunstone, 2002; Chin & Brown, 2000). When students intentionally work through the process of confronting their prior knowledge and negotiating this with new information and reflect on the changes in their thinking, meaningful learning occurs.

Metacognition

Case and Gunstone (2002) adapted a chemical engineering course to promote deep approaches to learning by promoting metacognitive development, defined as a shift in a student' approach to learning. This small study highlights the difficulty students can have when course expectations shift from algorithmic to conceptual and achieving this shift is essential to success in the course. Such difficulty shows both a lack of such expectations from earlier educational experiences and the need for such expectations to begin in early educational experiences. It may also serve as a lesson for teachers trying to change expectations in their classrooms from algorithmic to conceptual that it requires not only content knowledge on the part of the teacher and student but also metacognitive development. This process may be slow and come with some student resistance.

Chin and Brown (2000) qualitatively compared and detailed the differences between learning science through predicting, self-explaining, and metacognition. The use of these strategies produced differences in the generative thinking, nature of explanations, asking of questions, metacognitive activity, and approach to tasks associated with a deep approach to learning. Triangulation of data from multiple sources allowed the researchers to credibly assert that for students using a surface approach, strategies for a deep approach are less accessible to them than for students who regularly use a deep approach to learning. These deep learning strategies include predicting, self-explaining, and metacognition. The use of these strategies produced differences in the generative thinking, nature of explanations, asking of questions, metacognitive activity, and approach to tasks associated with a deep approach to learning. The authors claim the use of the aforementioned strategies, for some students, are only manifested under optimal conditions. For this reason, the authors suggest teachers should develop optimal conditions by scaffolding students' thinking with prompts, and encouraging students to ask questions, predict, explain and elaborate during activities and discussions.

This study examined the nature of students' learning approach at a more fine-grained level than other more general, performance-based studies. The analysis of students' thinking processes, and cognitive and metacognitive strategies allow for the identification and articulation of finer differences between deep and surface approaches to learning in the context of a science class. The triangulation of data, careful coding and analysis, and the context of a natural setting add significant credibility to the research. With strategies and differences between deep and surface approaches defined, further research can examine the effects of teaching strategies aimed at inducing a deep approach to learning.

Pugh (2002) examined two teaching styles, one case based, one ideas based, and their propensity to foster transformative experiences. Pugh (2002) believed this type of experience may be elicited through teaching methods that display how a concept functions as a true idea for the teacher by modeling everyday use of the concept to more fully perceive the world and by modeling the excitement or satisfaction that comes from doing so. The teacher would also provide supported opportunities for students to use the concept to expand perception, first in-class and then out-of-class. The goal is to help students move from having in-class, supported experiences with the concept to having out-of-class transformative experiences. Results indicate that a significantly greater percentage of students in the experimental class (52.9%) than students in the control class (22.7%) engaged in some degree of transformative experience. Further, it was found that students from both classes who engaged in at least some form of transformative experience scored significantly higher than other students on a follow-up assessment of understanding but not on a post intervention assessment of understanding.

The study does not indicate whether one of the elements had a greater impact on the results or whether either would be effective if taken separately. Because the differences between responses on the Likert scales were not equivalent, average scores may be unreliable as a measure of the students' true responses. One class was actually be serving a small minority very well whereas the other was somewhat appealing to the majority.

Pasley et al. (2004) qualitatively assessed science lessons from a subset of middle schools from the schools that participated in the 2000 National Survey of Science and

Mathematics Education to determine effective pedagogical techniques for engaging students in meaningful learning. Based on their findings, the researchers suggest ongoing professional development that focuses on elements of effective instruction rather than particular instructional strategies. Heyworth (1999), Patrick and Yoon (2004), She (2005), and Tsai (2000), examined the interaction between students' learning preferences and goals, and instruction.

Learning Preferences and Goals, and Instruction

Tsai (2000) examined the possible relationships between student Scientific Epistemological Beliefs (SEB) and perceptions of constructivist learning environments, with applications for the improvement of science teaching and learning. Based on the results, Tsai suggested teachers need to be highly aware of students’ epistemological orientation towards science, should accommodate these preferences when designing learning experiences, and teachers should especially provide constructivist-based lessons to enhance science learning for students who are epistemologically constructivist-oriented.

This study was not conducted with an experimental research design in place; hence, it is limited to correlation analyses between students’ scientific epistemological beliefs and learning perceptions. However, based on research previously cited in this chapter, constructivist learning environments may have a positive effect on the development of conceptual understanding. Rather than accommodating empiricist aligned SEB students with non-constructivist lessons, perhaps lessons could focus on helping those students become more constructivist aligned. This approach may add to the success of both constructivist aligned lessons and the development of conceptual understandings.

Patrick and Yoon (2004) found high mastery and low performance goals were associated with the largest gains in understanding in addition to having a mastery orientation benefiting conceptual understanding. The authors acknowledged the small sample size limits the generalizability of the findings. However, they claimed these results are supported by other research and they advocate that teachers strive to foster high mastery orientation and decrease the emphasis on performance goals. This can be particularly true for adolescents who are self-conscious and who would benefit most from a positive learning community.

Heyworth (1999) found teachers, being experts and familiar with a problem, might tend to use a working forwards approach when demonstrating how to solve a problem. But for students, when a problem is unfamiliar, mean-ends analysis is the strategy to be employed initially. During talk-aloud sessions, teachers can help students to focus on the goal of a problem then to set up appropriate sub-goals in order to create a qualitative procedure. In addition, Heyworth (1999) believed once students have derived and understood procedures for problems, they should be given plenty of practice to master the procedures and to encode them in long-term memory. Too often, teachers move on to new topics before slower students get sufficient practice to do this. Once encoded, procedures can be readily accessed from long-term memory and used almost automatically as is done by experts. This could be beneficial when solving longer, more complex problems that contain basic procedures as components of the overall solution.

The use of just two classes precludes true random sampling. Due to time requirements, only a small number of students could be interviewed. Thus, care is needed before generalizing the findings to the whole population of problem solvers for this topic. In addition, triangulation was not used as a method of ensuring internal validity of the study.

In She's (2005) study, the potential to promote students' understanding of difficult science concepts through an examination of the interrelationships among the teachers' instructional approach, students' learning preference styles, and their levels of learning process was explored. This study further demonstrates that meaningful learners retain more than other types of learners, even though the method of instruction was not meaningful-oriented. This may be because meaningful learners learn in their own way and develop better retention no matter what type of instruction they receive, implying that meaningful learners are able to adapt to any type of instruction.

These findings imply that the students' levels of learning process are important in determining how effectively students can construct knowledge and retain knowledge. Moreover, meaningful learners performed significantly better than in-between learners and rote learners on both the posttest and retention test. The author argues learning in a meaningful way is the key for leading students to successful learning; thus, giving students the opportunity to learn in a meaningful way should be the first priority of teaching.

This large-scale study attempted to find connections between several factors including learning process level, learning preference, and instructional strategy. Through random sampling, thorough analysis and a large sample size, this study credibly supports Ausubel's claim that meaningful learning comes from the ability to construct and retain knowledge. However, this study suggests the type of instruction has less of an affect on this ability than students' level of learning process. This study raises the question of how do students become meaningful learners?

Classroom Implications

Researchers who have studied these aspects of conceptual understanding in science education have suggested an essential starting point is students' prior knowledge. Some have used open-ended questions to elicit this knowledge in writing, while others use class discussions. There are advantages to both. When students record their learning in writing, there is a record for the teacher to look back on and monitor students' learning. More importantly, the record provides a means for the students to monitor their own cognitive growth, which may facilitate metacognition. The disadvantage is this is usually an individual process that could be richer if peer feedback is involved. This is the advantage of small group and class discussions. As vanZee and Minstrell (1997) demonstrated, class discussions can provide students with the opportunity to evaluate and monitor their own learning while considering other points of view. The teacher can also simultaneously elicit students' understandings and prior knowledge.

Once prior knowledge is known, the teacher can use techniques that will challenge students’ everyday conceptions about scientific ideas. Lectures, experiments and demonstrations alone may provide the needed conflict. However, the process cannot stop there, students need guidance and motivation to move through the conflict and restructure their knowledge in order for meaningful learning and conceptual change to occur (Sinatra & Pintrich, 2003).

This is where the art of teaching comes in. There isn't a prescribed formula that will work for every student, every time. Teachers who provide relevant, interesting, and meaningful investigations for students have more success than those who just go by the book. Teachers need to provide developmentally appropriate guidance for students to become actively involved and intrinsically motivated. Using peer collaboration, computer programs, and class discussions can be effective in guiding students through conceptual change, but only if they are willing.

When students falsely believe science is about memorizing already discovered facts, they have little motivation to incorporate these into their everyday understanding of the world. Scientific facts and how the students view the natural world will likely remain separate bodies of knowledge. However, if scientific concepts are believed to be a set of ideas constructed through investigations and under constant evaluation, students are more likely to see scientific ideas as similar to their own and worth incorporating.

When assessments of students' knowledge are simply recall of stated facts, the notion of science as a compilation of these facts is likely reinforced. Assessments should reflect the understanding the teacher hopes students to gain. Assessments may take on many forms besides a multiple-choice exam. Many of the assessments used in the studies were open-ended or short answer questions. Presentations, journals and projects are other forms of assessments that may be better suited for evaluating a student's conceptual understanding.

Implications for Future Research

The research here did not explicitly evaluate the use of particular assessment tools. Neither did it give generalizable suggestions for mediating students' cognitive conflicts. Such specifics are highly situational and something the teacher should investigate and reflect on while practicing. The variables involved in cognition and epistemology are numerous and tangled. Current research is just beginning to scratch the surface of these intriguing fields as they pertain to science education. The numerous variables are difficult to control for. Many of the sample sizes were smaller than one class size. At times this was confounded by the infusion of additional instructional assistance from the researchers. Several studies failed to consider the influence of a smaller teacher-student ratio when reporting findings. On several occasions, the means of Likert scores were used to analyze data. This method often misrepresents the bigger picture of the results. Several studies on student epistemological beliefs and beliefs on the nature of science failed to tie the results to student learning outcomes. Connections within circumstantial evidence from several sources create an argument for the incorporation of constructivist methods into every classroom. However, lacking a direct connection between improved conceptual understanding and a constructivist approach, apprehension towards these methods remains.

Although many aspects of what meaningful learning entails surfaced, exactly how students come to incorporate these approaches is still unclear. How do teachers empower students to become intrinsically motivated to take charge of their learning in a positive, meaningful way? Given an infinite amount of time, money, researchers, and willing teachers and schools, a large-scale, district wide, decades long study on student learning outcomes in a constructivist-oriented learning environment, compared with one (or more) using current practices, applying the aforementioned implications for classroom practices and avoiding the pitfalls of prior research, a compelling argument for or against these methods could be made. Since this is likely never to happen, the best place for teachers to begin is their own classroom.

After completing the review of the research, the best a teacher can do is follow the same guidelines for gaining a conceptual understanding in science to gain a conceptual understanding of teaching. Build on prior knowledge; remain open to evaluating and investigating new teaching methods that are relevant, meaningful, and interesting. Metacognitively monitor teaching practices and student learning for gains and needed improvements, and practice active, meaningful teaching and learning.

REFERENCES

American Association for the advancement of science. (1993) *Science for all Americans.* Retrieved August 3, 2006 from http://www.project2061.org/publications/sfaa/online/sfaatoc.htm.

Andre,T., Windschitl, M. (2003). *Interest, epistemological belief, and intentional conceptual change.* In Sinatra,G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.173-198). Mahwah, NJ: Lawrence Erlbaum Associates.

Asoko, H. (2002) Developing Conceptual Understanding in Primary Science. *Cambridge Journal of Education, 32*(2), 154-164.

Ausubel, D.P. (2000). *The acquisition and retention of knowledge: A cognitive view.* Dordrecht/Boston/London: Kluwer Academic Press.

Basili, P.A., Sanford, J.P. (1991). Conceptual Change Strategies and Cooperative Group Work in Chemistry. *Journal of Research in Science Teaching, 28*(4), 293-304.

Bell, B. (2005). Pedagogies developed in the learning in science projects and related theses. *International Journal of Science Education, 27*(2), 159-182.

Bliss, J., Ogborn, J. (1994). Force and motion from the beginning. In Salio, R., Vosniadou, S., (Eds.). Conceptual Change in the Physical Sciences. *Learning and Instruction*. *4*(1), 7-26.

Caravita, S., Hallden, O. (1994). Re-framing the problem of conceptual change. In Salio, R., Vosniadou, S., (Eds.). Conceptual Change in the Physical Sciences. *Learning and Instruction*. *4*(1), 89-111.

Case, J., Gunstone, R. (2002). Metacognitive development as a shift in approach to learning: an in-depth study. *Studies in Higher Education, 27*(4), 459-469

Cavalcante, P.S., Newton, D.P. (1997). The effect of various kinds of lessons on conceptual understanding in science. *Research in Science & Technological Education, 15*(2), 185-194.

Cavallo, A.M.L., McNeely, J.C., Marek, E.A. (2003). Eliciting students' understandings of chemical reactions using two forms of essay questions during a learning cycle. *International Journal of Science Education, 25*(5), 583-603.

Center for science, mathematics, and engineering education. (1998). *Every child a scientist: Achieving scientific literacy for all Americans.* Retrieved August 3, 2006, from http://darwin.nap.edu/books/0309059860/html.

Chi, M.T.H., Slotts, J.D., de Leeuw, N. (1994) *From things to processes: A theory of conceptual change for learning science concepts.* In Salio, R., Vosniadou, S., (Eds.). Conceptual Change in the Physical Sciences. *Learning and Instruction*, *4*(1), 27-44.

Chin, C., Brown, D.E. (2000). Learning in science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching*, *37*(2), 109-138.

Coll, R. K., France, B. (2005). The role of models/and analogies in science education: implications from research. *International Journal of Science Education, 27*(2), 183-188.

Dalton, B., Morocco, C.C., Tivnan, T., Rawson-Mead, P.L. (1997). Supported inquiry science: Teaching for conceptual change in urban and suburban science classrooms. *Journal of Learning Disabilities*, *30*(6), 670-684.

DeBoer, G.E. (1991). *A history of ideas in science education, implications for practice.* New York/London: Teachers College Press.

DeLeeuw, N., Chi, M.T.H. (2003). *Self-explanation: Enriching a situation model or repairing a domain model?* In Sinatra,G.M., Pintrich, P.R., (Eds.) *Intentional Conceptual Change.*

(pp.55-78) Mahwah, NJ: Lawrence Erlbaum Associates.

De Vries, E., Lund, K., Baker M. (2002). Computer-mediated epistemic dialogue: explanation and argumentation as vehicles for understanding scientific notions. *The Journal of the Learning Sciences, 11*(1), 63-103.

DiSessa, A.A., Elby,A., Hammer, D. (2003). J's epistemological stance and strategies. In Sinatra,G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.237-290). Mahwah, NJ: Lawrence Erlbaum Associates.

Donovan, M. S., Bransford, J. D. (2005). How Students Learn: Science in the Classroom. Committee on How People Learn: A Targeted Report for Teachers, National Research Council.

Duit, R., Treagust, D. F. (2003). Conceptual change: a powerful framework for science teaching and learning. *International Journal of Science Education*, *25*(6), 671-688.

Edens, K.M., Potter, E. (2003). Using descriptive drawings as a conceptual change strategy in elementary science. *School Science and Mathematics, 103*(3), 135-143.

Fellows, N.J. (1994). A window into thinking using student writing to understand conceptual change in science learning. *Journal of Research in Science Teaching*. *31*(9), 985-1001.

Ferrari,M., Elik, N. (2003). Influences on intentional conceptual change. In Sinatra,G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.21-54). Mahwah, NJ: Lawrence Erlbaum Associates.

Geelan, D. R., Wildy, H., Louden, W., Wallace, J. (2004). Teaching for understanding and/or teaching for the examination in high school physics. *International Journal of Science Education, 26*(4), 447-462.

Girard, M., Wong, D. (2002). An aesthetic (Deweyan) perspective on science learning: case studies of three fourth graders. *The elementary school journal, 102*(3), 199-224.

Glynn, S.M., Duit, R. (1995). Learning science meaningfully: Constructing conceptual models. In Glynn, S.M., Duit,R., (Eds.). *Learning Science in the Schools: Research reforming practice.* (pp.3-34) Mahwah, NJ: Lawrence Erlbaum Associates.

Hammer, H., Elby, A. (2003). Tapping epistemological resources for learning physics. *The Journal of the Learning Sciences, 12*(1), 53-90.

Hart, C., Mulhall, P., Berry, A., Loughran, J., Gunstone, R. (2000). What is the purpose of this experiment? Or can students learn something from doing experiments? *Journal of Research in Science Teaching. 37*(7), 655-675.

Hatano, G., Inagaki, K. (2003). When is conceptual change intended? A cognitive-sociocultural view. In Sinatra,G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.407-428). Mahwah,NJ: Lawrence Erlbaum Associates.

Hennessey, M.G. (2003). Metacognitive aspects of students' reflective discourse: Implications for intentional conceptual change teaching and learning. In Sinatra,G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp103-132). Mahwah, NJ: Lawrence Erlbaum Associates.

Heyworth, R.M. (1999). Procedural and conceptual knowledge of expert and novice students for the solving of a basic problem in chemistry. *International Journal of Science Education, 21*(2), 195-211.

Hynd, C. (2003). Conceptual change in response to persuasive messages. In Sinatra,G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.291-316). Mahwah, NJ: Lawrence Erlbaum Associates.

Jonassen, D., Strobel, J., Gottdenker, J. (2005). Model building for conceptual change.

Interactive Learning Environments. 13(1-2), 15-37.

Lederman, N., Lederman, J. (2004). Twenty-four, Forty-two, and I love you: Keeping it complex. *Harvard Educational Review, 61*(1), 1-24.

Lin, H., Chiu, H., Chou, C. (2004). Student understanding of the nature of science and their problem-solving strategies. *International Journal of Science Education, 26*(1), 101-112.

Linnenbrink, E., Pintrich, P.R. (2003). Achievement goals and intentional conceptual change. In Sinatra, G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.347-374). Mahwah, NJ: Lawrence Erlbaum Associates.

Luque, M.L. (2003) The role of domain-specific knowledge in intentional conceptual change. In Sinatra, G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.133-170). Mahwah, NJ: Lawrence Erlbaum Associates.

Mason, L. (2003). Personal epistemologies and intentional conceptual change. In Sinatra, G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.199-236). Mahwah, NJ: Lawrence Erlbaum Associates.

McCleery, J.A., Tindal, G.A. (1999). Teaching the scientific method to at-risk students and students with learning disabilities through concept anchoring and explicit instruction. *Remedial and Special Education, 20*, 7-18.

McElwee, P. (1991). Transition from personal to scientific understanding. *Research in Science & Technological Education*, *9*(2), 139-154.

Montgomery, S. L. (1994). *Minds in the making.* New York/London: The Guilford Press.

Nakhleh, M.B., Lowrey, K.A., Mitchell, R.C. (1996). Narrowing the gap between concepts and algorithms in freshman chemistry. *Journal of Chemical Education, 73*(8), 758-762.

National center for education statistics. (2005). *The Nation's report card state science 2005:*

Washington grade eight public schools, snapshot report. Retrieved August 3, 2006, from http://nces.ed.gov/nationsreportcard/pdf/stt2005/2006467WA8.pdf.

National Research Council. (1996). *National science education standards.* Washington D. C.: National Academy Press.

Niaz, M. (2002). Facilitating conceptual change in students understanding of electrochemistry. *International Journal of Science Education, 24*(4), 425-439.

Novak, J.D. (1995). Concept mapping: A strategy for organizing knowledge. In Glynn, S.M., Duit, R., (Eds.) *Learning Science in the Schools: Research reforming practice.* (pp.229-245). Mahwah, NJ: Lawrence Erlbaum Associates.

Office of Superintendent of Public Instruction. (2005). *K-10 grade level expectations: a new level of specificity, Washington State's Essential Academic Learning Requirements.* Retrieved August 3, 2006, from http://www.k12.wa.us/CurriculumInstruct/science/pubdocs/ScienceEALR-GLE.pdf.

Park, J., Han, S. (2002). Using deductive reasoning to promote the change of students' conceptions about force and motion. *International Journal of Science Education, 24*(6), 593-609.

Park, J., Kim, I. (1998) Analysis of students' responses to contradictory results obtained by simple observation or controlling variables. *Research in Science Education, 28*(3), 365-376.

Patrick, H., Yoon, C. (2004). Early adolescents' motivation during science investigation. *Journal of Educational Research, 97*(6), 319-328.

Pasley, J.D., Weiss, I.R., Shimkus, E.S., Smith, P.S. (2004). Looking inside the classroom: science teaching in the United States. *Science Educator*, *31*(1), 1-12.

Pendley, B. D., Bretz, R. L., Novack, J. D. Concept maps as a tool to assess learning in chemistry. *Journal of Chemical Education, 71*(1), 9-17.

Pintrich, P. R., Marx, R. W. and Boyle, R. A. (1993). Beyond cold conceptual change: the role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*, 167–199.

Pugh, K.J. (2002). Teaching for transformative experiences in science: an investigation of the effectiveness of two instructional elements. *Teachers College Record*, *104*, 1101-1137.

Qian, G. and Alvermann, D. E. (2000). Relationship between epistemological beliefs and conceptual change learning. *Reading & Writing Quarterly, 16,* 59-74.

Regis, A,. Albertazzi, P., G., Roletto, E. (1996). Concept maps in chemistry education. *Journal of Chemical Education*. 73(11), 1084-1088.

Salio, R., Vosniadou,S. Eds. (1994). Conceptual Change in the Physical Sciences. *Learning and Instruction*, *4*(1), 3-121.

She, H. (2005). Promoting students' learning of air pressure concepts: the interrelationship of teaching approaches and student learning characteristics. *The Journal of Experimental Education*, *74*(1), 29-51.

Sinatra, G.M., Pintrich, P.R. (2003). *Intentional Conceptual Change.* Mahwah, NJ: Lawrence Erlbaum Associates.

Solomon, J., Duveen, J., Scot, L., McCarthy, S. (1992). Teaching about the nature of science through history: Action research in the classroom. *Journal of Research in Science Teaching. 29*(4), 409-421.

Songer, N.B., Linn, M.C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching*. 28(9), 761-784.

Southerland, S.A., Sinatra, G.M. (2003). Learning about biological evolution: A special case of intentional conceptual change. In Sinatra, G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.317-346). Mahwah, NJ: Lawrence Erlbaum Associates.

Stinner, A., (1995). Science Textbooks: Their present role and future form. In Glynn, S.M., Duit, R., (Eds). *Learning Science in the Schools: Research reforming practice.* (275-296). Mahwah, NJ: Lawrence Erlbaum Associates.

Swafford, J., Bryan, J. (2000) Instructional strategies for promoting conceptual change: Supporting middle school students. *Reading & Writing Quarterly*, *16,* 139–161.

Tao, P. (2001). Developing understanding through confronting varying views: the case of solving qualitative physics problems. *International Journal of Science Education, 21(*12), 1201-1218.

Tao, P., Gunstone, R.F. (1999). Conceptual change in science through collaborative learning at the computer. *International Journal of Science Education, 21*(1), 39-57.

Thagard, P., Zhu, R. (2003). Acupuncture, incommensurability, and conceptual change. In Sinatra, G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.79-102). Mahwah, NJ: Lawrence Erlbaum Associates.

Tiberghien, A. (1994). Modeling as a basis for analyzing teaching-learning situations In Salio, R., Vosniadou, S., (Eds.). Conceptual Change in the Physical Sciences. *Learning and Instruction*. *4*(1), 71-88.

Tsai, C. C. (1998). An analysis of Taiwanese eighth graders' science achievement, scientific epistemological beliefs and cognitive structure outcomes after learning basic atomic theory. *International Journal of Science Education*, *20*, 413–425.

Tsai, C. C. (2000). Relationships between student scientific epistemological beliefs and perceptions of constructivist learning environments. *Educational Research, 42*(2), 193-205.

VanZee, E., Minstrell, J. (1997). Using questioning to guide student thinking. *The Journal of the Learning Sciences, 6*(2), 227-269.

Vosniadou, S. (1994). *Capturing and modeling the process of conceptual change.* In Salio, R., Vosniadou, S., (Eds.). Conceptual Change in the Physical Sciences. *Learning and Instruction*. *4*(1), 45-70.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction, 11*(4-5), 381-419.

Vosniadou, S., (2003). Exploring the relationships between conceptual change and intentional learning. In Sinatra, G.M., Pintrich, P.R., (Eds.). *Intentional Conceptual Change*. (pp.377-406). Mahwah, NJ: Lawrence Erlbaum Associates.

Wandersee, J.H., Mintzes, J.J., Novak, J.D., (1994). Research on alternative conceptions of science. In Gabel, D.L., (Ed.). *Handbook of Research on Science Teaching and Learning*. (pp. 177-210). New York: Macmillan Publishing Company

Yip, D. Y. (2004). Questioning skills for conceptual change in science education. *Journal of Biological Education*, *38*(2), 76-83.

Zusho, A., Pintrich, P.R. (2003). Skill and will: the role of motivation and cognition in the learning of college chemistry. *International Journal of Science Education, 25*(9), 1081-1094.