How Does the Inquiry Learning Method Affect Student Cognitive Development at Varying Ages?

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Abstract

Inquiry is a common method used to teach high school science. However, its use is limited in the elementary school setting. The researcher examined the use of inquiry to teach force topics to elementary students. The investigation was also conducted with ninth grade students. Results showed that all groups involved in the inquiry activity improved more dramatically than those that did not participate. Results also showed that the youngest group of students improved more dramatically than some of the older study participants. The second grade students showed great improvement in the basic ability to describe a force. They showed growth in their ability to relate force to motion and their ability to use Newton's 3^{rd} Law to explain a picture scene. Growth in the last two areas was not as significant and correlated with knowledge of cognitive development in students. It is believed that this is because these two questions demanded more relational skills that more cognitively developed, older students are capable of. Still, the data suggests that even the youngest of students may benefit from the implementation of inquiry activities into their science curriculum.

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Introduction

As a science teacher, I have always wondered how young children learn difficult concepts. How do their young brains rationalize phenomena such as the moon, looming low and large in the sky one night? The next week, it seems small and far away. Similarly, how would a more advanced science student rationalize this observation? At what point do our students become so inhibited by wanting to give the correct answer that they forget the value of making a mistake? It is for these reasons that I have chosen to investigate the learning of students of different ages.

Purpose of the Study / Problem Statement

The purpose of this study is to investigate the learning of science students at different ages and abilities. I am interested in the use of inquiry activities in my school's elementary program. I have a feeling that there is disconnect between the activities used to teach and the types of tests given during assessment. For example, I was given the opportunity to examine a fifth grade science test. One of the questions found was "what year did Newton publish his book?" Memorizing the year of publication does not help a student learn problems solving techniques that can be applied to a science problem. I have also observed ninth grade science students in class. They wait to be told how to solve a problem rather than trying to find a way to solve it themselves. At some point along their educational path, these students have been trained to follow a set of instructions to reach one specific answer. It is as if they have lost the ability to use creativity and imagination to lead their learning. These observations have caused me to develop the following research question; how does inquiry affect student cognitive development at varying ages?

I believe it will be interesting to examine the differences in learning abilities of students of different ages by seeing how they respond to a friction specific inquiry activity. Current research on cognitive abilities states that primary age students are capable of basic grouping skills but lack the ability to make connections. Researchers have shown that this ability comes about as the brain matures. I feel that this research has led teachers and curriculum specialists to develop curriculum that is essentially "dumbed down" and removes the exploratory component that is so important to science. I feel that when presented with an opportunity to explore the cause of a particular phenomenon, primary students will surprise me with their creativity. As a result, I hope to excite our elementary teachers about the use of inquiry in the primary grades.

Setting

Research will take place at a rural public school in southwest Minnesota. Test subjects will include students from grades two, five, six, and nine. These age groups were chosen because they share similar topic specific learning standards.

Definitions

Terms that will be used frequently over the course of the research and within this final paper include:

1. Formative assessment probe: an assessment designed to identify misconceptions about a specific learning standard. This will be referred to as FAP in the research paper.
2. Inquiry lesson: a student centered lesson designed to allow students to drive their learning process by asking and investigating questions.

Limitations / Assumptions

Unfortunately, the students involved in the study are not evenly spaced in age. I would have preferred to study groups of students in grades one, three, five, seven, nine, and eleven/twelve. However, the Minnesota state science standards have limited my test group to grades two, five, six, and nine. Class size limits my use of the $11^{th}/12^{th}$ grade physics class because credible research requires the use of a control group and a test group. My physics class only has one section, eliminating the presence of one of the necessary groups.

Another potential problem with this study is the number of students involved. Unfortunately, the school involved is small. If this study was to take place in a metropolitan school with a larger population or within many schools, results would be more valid simply because the test population would be much larger. Also it is difficult to account for the general abilities of the students involved, the number of special education students in each class and any absences that may have occurred during the inquiry portion of the study.

Significance of the study

As a science teacher, I feel that inquiry activities are easier and more fun to use in the classroom rather than notes and worksheets. However, it takes my ninth grade science students some time to adjust to the different classroom environment. Up to this point, their science education has been dominated by scripted worksheets and investigations with step-by-step instructions. It is my hope that this study will help our elementary science teachers see the benefits of supplementing their current curriculum with science inquiry activities. I hope to show them that their students are indeed capable of using creativity to solve problems and learn. As a result, students will feel more comfortable with open ended, non-scripted activities in upper level science classes.

Organization of the Study

Past and current research on the topic of cognitive ability of children will be explored in Chapter Two. It will also examine the best ways to encourage students to learn science through the use of inquiry activities. Methodology needed to research the chosen question for the study is detailed in Chapter Three. In Chapter Four, I will organize and analyze all data. The study will conclude with Chapter Five, which will include a summary of conclusions drawn from the data presented in Chapter Four.

Summary

To follow, I will look closely at the abilities of students to learn science. I hope to show that young students are capable of handling more difficult tasks than we allow them to try. The research used to guide this study can be found in the next chapter.

Literature Review

The human brain has been an object of wonder and mystery for many years. It has also been the subject of countless research projects and experiments over the years. The content of this literature review will focus on brain anatomy and its relationship to learning, early brain research, current brain research, cognitive development, how cognitive development relates to science education and the use of inquiry to enhance cognitive development in science education.

Martini, Timmons, and McKinley (2000) describe brain development as a series of stages. At three weeks of development, an embryo has three primary brain sections, the prosencephalon, the mesencephalon and the rhombencephalon. These regions specialize and divide into 6 brain, midbrain, and hindbrain regions called the cerebrum, diencephalon, mesencephalon, cerebellum, pons and medulla oblongata. The cerebrum is the largest area of the brain and is responsible for "conscious thought, intellectual functions, memory storage and retrieval and complex motor patterns" (p. 378). The cerebrum is divided into left and right hemispheres with the longitudinal fissure separating the two. Each hemisphere is further divided into frontal, temporal, parietal and occipital lobes. The cerebral hemispheres receive sensory information from the opposite side of the body; for example, the left cerebral hemisphere will receive sensory information from the body's right hand.

The lobes of each hemisphere mature at different rates and are responsible for processing different tasks. According to Sousa (2006) the frontal lobes are responsible for planning, rationality, higher order thinking, processing, and emotional control. The frontal lobe is also the lobe that takes the longest to fully mature, sometimes, as long as early adulthood. The temporal lobes specialize in recognition of objects, music, and faces. The occipital lobes process visual stimuli while the parietal lobes process calculations, special awareness and other types of recognition.

The Merriam-Webster Dictionary (2011, para 1) defines cognitive as “of, relating to, being, or involving conscious intellectual activity (as thinking, reasoning, or remembering).” Inhelder and Piaget (1964) spent years observing and studying children in an attempt to better understand how reasoning and thought evolved throughout childhood and adolescence. They conducted observations and tests involving 2,159 children before publishing their results in the book *The Early Growth of Logic in the Child* (1964). The researcher focuses on formal operations of classification, stages of development, and the mechanisms that account for the development.

Inhelder and Piaget (1964) define a concrete operation of thinking as one that “the level of reasoning varies with the character of the content to which it applies” (p. 114). When they asked children to classify animals, they found that a common classification was between those animals that walked and those that flew. When a fish was added to the collection, the children had difficulty fitting it into one of their classification groups, creating a state of disequilibrium. The authors also state that children ages five to seven have the ability to observe one grouping and choose the object that does not belong. However, it is not until children reach age seven to eight that they are able to grasp the concept that one grouping may be treated as a singular class with like characteristics. This information shows a shift from pre-operational thinking to concrete operational thinking around the age of seven years.

Piaget and Inhelder (1964) define an individual capable of formal operational thinking as someone who “will be able to foresee the various combinations, and he will use propositional operations to solve the problem” (p. 74). The researchers note that the transition from pre-operational thinking to concrete operational thinking to formal operational thinking is not a series of sudden steps. Rather, they are autonomous. According to Piaget and Inhelder, "Operations are a continuation of actions; they express certain forms of co-ordination which are general to all actions; whether or not the co-ordination is complete, operations and pre-operational co-ordinations enter into the most diverse kinds of behavior" (1964, p. 291). The authors go on to further explain how this gradual change occurs by describing a period of blatant, uncontrolled behavior interspersed with periods of more controlled reactions (pre-operational stage), this evolves into a period where the child can begin to internalize actions and spatially and structurally characterize objects (concrete operational stage). The formal operational stage begins when the child is able to take these actions and realize the interconnectedness they exhibit to the world around them. This continuous progression through the stages of operational thinking has been displayed in various other Piaget trials and is still considered the basis for cognitive development as it relates to education.

Fischer (2009) examines various cognitive models and their effectiveness in the classroom. The brainhood model operates under the assumption that the brain is the most important organ associated to learning, leaving out any contributions from the body and the surrounding environment. "[Children] store knowledge in their brain and there it sits until they need to recall it, as if the brain is primarily a repository" (p. 5). Fisher (2009) describes this model as one that would allow individuals to download all information needed for a particular day and then processes it as needed throughout the day. Another similar model that Fischer (2009) examines is the conduit model. This model is similar to the brainhood model because it insinuates that teachers share knowledge with students. Students then have access to that knowledge and can use it when needed. Neither of these models lends themselves to valuable learning because they do not allow time for practice, questioning, or experimentation. Fischer (2009) states that "The conduit metaphor is so pervasive in human language and culture that it's hard to escape its influence" (p. 5). Fischer (2009) does admit that the conduit model has its uses in limited capacity. For instance, when learning bits of information or facts that can be quickly recited, the conduit model works fine. However, when knowledge needs to be used rather than accessed, the knowing as actively constructing model is gaining notoriety.

Fischer (2009) quotes Hubel &Wiesel, (1970) by stating "When we actively control our experience, that experience sculpts the way our brains work, changing neurons, synapses, and brain activity" (5). This is the basis for the knowing as actively constructing model. This model allows students to build knowledge based upon interactions with their environment and the people around them. The adolescent brain forms connections that are valuable and are actively used as the student moves through his/her daily activities. This model has support rooted in early brain research as Fischer (2009) quotes Vygotsky, (1978) by saying "Each generation needs to build knowledge anew, it cannot be simply given or transmitted" (p. 6). Fischer (2009) also quotes Piaget (1952) by stating "… fundamental metaphor for knowledge is grasping ideas and facts with the mind and manipulating them physically and mentally" (p. 6).

The last model mentioned by Fischer (2009) is the dualist model. Individuals with a dualistic nature feel that a correct answer exists and that they must find it. They do not function well with open ended questions that could have more than one correct answer. In fact, they tend to panic when faced with more than one solution. One can see how these individuals would struggle in an inquiry setting as either a teacher or a student.

Cognitive Acceleration through Science Education (CASE) originated in the United Kingdom as a means to determine if cognitive gains could be made through the use of higher order, inquiry like tasks. CASE is currently taught in many British schools and has become the most widely used form of science teacher professional development programs in Great Britain. Endler and Bond (2007) believe that inquiry is a basis for sound science education. The researchers acknowledge that the higher order thinking skills necessary for good inquiry are not stressed. Therefore, the ability to inquire is stunted. Because of this, the researchers chose to implement a version of the British CASE program at an Oregon school. The research varied from the British version in instrumentation and teacher professional development.

According to Endler and Bond (2007), concrete operational thinking primarily focuses on identifying words, objects and symbols. Students operating at the concrete operational stage would classify objects as heavy and light in a density experiment. Students who have advanced to the formal operational thinking stage have the ability to expand upon their knowledge by asking questions, forming hypotheses, exploring their implications and testing their thoughts for validity. These students have the ability to make connections between concepts that they would not have been able to make at a younger age. Endler and Bond (2007) cite Adey and Shayer (1994) when they state that most junior high students function within the concrete operational stage. Interestingly, an alarmingly low number of high school students actually progress to the formal operational stage of thinking.

As a result of the Oregon CASE study, Endler and Bond (2007) report showing significant cognitive growth between the 8^{th} and 10^{th} grade. No variation was noted between male and female students between 8^{th} and 10^{th} grade. This variation was noted between 10^{th} and 12^{th} grade. Females showed greater cognitive growth during this time than their male counterparts. These results were consistent with the Great Britain CASE study. The authors conclude that cognitive growth is positively related to "expos[ing] students to Piagetian concepts, focus on thinking and problem solving, and working in groups to derive solutions and explain their thinking" (2007, p. 165). These finding are significant because there has been concern that the cognitive demands placed upon high school students and the cognitive abilities of these high school students are mismatched. High school science teachers are asking students to perform tasks they might not be developmentally ready for.

In the *Journal of Developmental Science,* Leroux, Spies, Zago, Rossi, Lubin, Turbelin, Mazoyer, Tzourio-Mazoyer, Houdé, and Joliot (2009) used functional magnetic resonance imaging (fMRI) to determine if any correlation existed between adolescent cognitive development and the abilities of adults. The study showed that Piagetian tasks, those requiring higher order thinking skills of the formal operational stage, remain difficult for young adults. The researchers determined that a greater correlation between adult and adolescent cognitive ability may exist while stressing that adult brains may not fully recover from misconceptions learned during stages of high cognitive development.

Leroux, et. al (2009) expand their research to include brain anatomy and maturation. The authors note that the prefrontal cortex, found in the frontal lobes of the cerebrum, mature later in a student's life than areas associated with recognition, motor and sensory processes. The author also references a study by Casey et al. (1997) which found "greater susceptibility to interference in children (between ages of 6 and 12) than in adults with increased recruitment in the prefrontal regions" (p. 335). The researcher stresses the importance of being familiar with each student's current cognitive ability. The curriculum can be tailored to that level of cognition in an effort to appropriately challenge the student at his or her current level of thinking. It is important to help students develop a good cognitive foundation during the concrete operational stage. This enables them to have fewer obstacles to overcome as the academic demands placed upon them require greater formal operational stage thinking.

The importance of the above statement is rooted in misconception. As humans, we are very willing to trust our observations and interactions with our environment. Children will come up with an explanation for a certain observed phenomenon, such as why is the sky blue? Their reasoning will meet their need to explain the situation in a personal manner. However, when asked to explain their reasoning scientifically, they falter. They must be taught how to do this. Lawson (2008) discusses the need to expose students to inquiry related activities at an early age. The researcher contends that humans are too quick to believe senses provide reliable information. Many times they result in misconceptions, particularly in children. It is not sufficient to simply tell children the right answer in these situations. It may require some form of "active participation in an internally driven and self-guided process called self-regulation" (p. 2).

Lawson (2008) goes on to discuss a concept called hypothetico-predictive (HP) reasoning. HP reasoning is demonstrated when an individual can make an observation, generate a possible explanation, test it by predicting possible results and draw conclusions based on those results. HP reasoning can be as simple as determining what to wear in the morning. Example: it is late September so the temperature could be either cool or warm. Turn on the television for the weather forecast to determine what outfit will be best suited for the day. The forecast calls for an early morning high of 50^{o} and an afternoon high of 75^{o}. Therefore, dress in layers to accommodate the change in temperature during the day. This example shows a very simple version of HP reasoning. Sometimes the results do not meet the expected outcomes, for example, if the temperature remained cool and then it rained, the individual in the experiment would undergo a state of disequilibrium. The individual in the experiment would have to generate a new set of hypothesis to explain the discrepancy between the actual outcome and the expected outcome. Sometimes disequilibrium is sufficient to overcome misconceptions of students.

The author contends that children are capable of basic HP reasoning from birth. Lawson (2008) cites a research study by Hauser (2000) documenting HP reasoning patterns in rhesus monkeys. It is believed that if nonhumans can perform basic HP reasoning functions then infant humans can as well. If this ability is present at birth, then it can be assumed that as humans grow, so do their awareness and reasoning patterns associated with the world around them. The ability to "self – regulate, generate and test new hypothesis in an HP fashion" (p 5.) continues to grow and develop into adolescence and early adulthood. Lawson (2008) completed a research project that involved asking a variety of children, ranging in ages from 6 – 14 years old, to identify a fictional animal using a set of three parameters. Lawson found that children six and under could not use the set of parameters to identify examples of the fictional animal. Half of the seven year olds could and all of the children ages 8 – 14 could identify examples of the fictional animal using the given parameters. Lawson (2008) attributes this ability to a growth spurt of the frontal lobe, around age 7, which signals the beginning of the concrete operational thinking stage. This maturation allows the student to begin classifying events and situations using HP reasoning. The author expands upon the brain's processing ability beyond early years by discussing formal operational thinking when he quotes Mosham (1998):

> In fact, there is surprisingly strong support for Piaget's 1924 proposal that formal or hypothetico-deductive reasoning – deliberate deduction from propositions consciously recognized as hypothetical – plays an important role in the thinking of adolescents and adults but is rarely seen much before the age of 11 and 12. (p. 7)

As mentioned previously, this form of thinking is different from concrete operational thinking because the individual now displays the ability to test hypotheses and draw explanations and conclusions based on observations made. Lawson (2008) also discusses a third form of thinking called the post – formal or theoretical stage that occurs during late adolescent through early adult hood due to final brain growth and development. The ability to devise a solid experimental procedure developed enough to test two seemingly different hypotheses, such as abstract or theoretical topics, requires post – formal thinking abilities. This is also a clear indication that theoretical concepts should not be introduced in primary grades.

Lawson (2008) contends that teachers should be cognizant of each student's ability to learn how to question. Alarmingly, many individuals do not advance to the formal operational stage of thinking, whereas, many teachers operate at either the formal operational stage of the post – formal operational stage. Such instructors tend to assume that everyone is operating at the same thinking level causing disconnect in the classroom. It is important for teachers to incorporate activities that encourage students to inquire, explore, and compare their findings to what they already know. This can be done at all grade levels, with varying levels of complexity.

Another research study by Ravanis, Koliopaulos, and Boilevin (2007) examined the ability of preschool aged children to construct models of rolling friction. Their research involved three groups of students. Group one received instruction in a teacher centered manner. All activities, worksheets, and questions were given to the students by the teacher. The second group was taught using Piagetian principals stressing the importance of building intellectual knowledge based upon one's interaction with the environment. The third group received instruction based upon post – Piagetian and post – Vygotskian research. This group's instruction focused on both the child's change in cognitive ability during the instructional cycle while taking advantage of all social and environmental interactions to allow the child to develop his or her own cognitive tools.

Ravanis et al. concluded that children age five to six are indeed capable of deducing certain qualities of rolling friction. They were able to describe factors of rolling friction as it applies to an object rolling across a horizontal surface. This allows them to construct a basic model of rolling friction that they will be able to draw upon in the future. When comparing the different teaching methods, the researchers found that group three showed a 59% increase in cognitive ability whereas group two showed only a 5% growth. The conclusion was made that it is not the number of interventions, activities, and opportunities that help children overcome misconceptions and construct new models. Rather, "children's progress is significant when placed in an environment with a systematic teaching intervention that is oriented at constructing the characteristics of a precursor model for rolling friction" (p. 431).

Another researcher to look at the relationship between cognitive ability and science education is Talanquer (2009). The researcher looks at the possibility of better understanding the cognitive constraints of students to understand and predict learning obstacles faced by students. The author cites Gelman, (1990) when defining cognitive constraints as being skeletal in nature; guiding and restricting thinking. They do not need to be fully satisfied. They can range from "domain general to domain specific, from implicit to explicit, which are satisfied simultaneously as well as they can be" (p. 2124). They have the ability to produce answers quickly, but can be polluted with bias and error because they rely on prior knowledge which may include misconceptions. Identification of these misconceptions and assumptions allows teachers to better identify each student's learning progression and the constraints he or she has developed.

Talanquer (2009) examines two types of learners that are identified as novice and advanced. Novice learners' cognitive level could be defined as concrete operational and the advanced learners are defined as an individual who has transitioned to formal operational thinking. When analyzing the student models for matter, the author found that the novice students focused on physical appearance. This shows that the novice learner's cognitive constraints are focused on observations made with the senses and prevent him or her from advancing to more abstract concepts such as molecular motion associated with different states of matter.

The advanced learner's model for matter does include considerations for molecular motion associated with different states of matter. These models can be applied across different matter classifications. The cognitive constraints of this learner are still present but they have allowed the student to build a strong foundation of knowledge enabling him or her to apply this information to more theoretical situations or those with increased rigor. According to the Talanquer (2009), when trying to identify student constraints, it is more beneficial to "[focus] on underlying implicit assumptions that constrain student thinking in a specific micro – domain is a more fruitful educational tool" (p. 2133). Students come into the classroom with a plethora of preconceived notions. As an educator, it is impossible to address all prior knowledge for all students at one time. Instead, focus on one small topic at a time when trying to determine the classes' level of understanding. The author suggests thinking of cognitive constraints and learning progressions as "road maps" (p. 2134) because there are multiple paths to achieve the end result for cognitive advancement.

How can teachers best present lessons that not only meet the cognitive demands of students but also meet the ever changing science standards? Hubber, Tytier, and Haslam (2010) focused their research on three accomplished classroom teachers and their use of representational diagrams, teacher led exercises and student group work. The use of representational diagrams (representations) is designed to allow learners to “use their own representational, cultural, and cognitive resources to engage with the subject – specific representational practices of science” (p. 6). These representations provide the instructor with an unbiased view of the student’s current level of understanding and any constraints that may be present. Students who can construct accurate representations for different science concepts can apply them to related processes. Science students need to learn how to evaluate science texts for relevant and reliable concepts, findings, and knowledge. Students who are scientifically literate pose the ability to understand and explain science concepts in a manner different from the way they were originally taught.

Hubber et al. (2010) found that the use of representations in physics resulted in much more in depth classroom discussions. The improved discussion translated into broader avenues for inquiry because the willingness to question and explore had improved. The instructors that were utilized in the research project felt that representations exposed student views that were previously unfamiliar to them. While the initial process took some time to adjust to, all instructors involved stated that they would be incorporating representations into their daily curriculum.

In *How the Brain Learns*, Sousa (2006) describes how the actively growing child’s brain makes many more connections than those of an individual approaching puberty. As a newborn grows through early childhood, they are observing every environmental stimulus possible and forming connections for those stimuli. As the child reaches puberty, the pace slows. The connections that the brain finds useful will be maintained, those deemed nonessential are destroyed in a process called apoptosis. It is believed that as the brain selectively weeds out some connections, others are strengthened. This process called "pruning" is discussed in detail by Payne (2010). He defines pruning as "neuronal decrease" (p. 80). That begins around age 12 in the frontal and parietal lobes. The author contends that pruning is necessary so that the most frequently used connections may be properly maintained. It is not as easy to influence experiences of adolescents as it is those of infants and children. However, it is important for teachers and adults to be aware of the influence of environmental conditions in the pruning process. A student centered classroom helps to prevent pruning of important academic neural pathways. Payne (2010) inserted a quote by Glenda Crawford (2007) which summarizes this idea.

> Important to parents and educators is the implication that the experiences in which adolescents are involved can play a role in determining which neural structures survive… Those who engage actively in music sports, or academics, for example potentially strengthen and sustain synaptic connections in the associated areas. (p. 83)

Research shows the most effective way to influence student thinking within the science classroom is through the use of inquiry and constructivism. Both of these methods are student centered. As mentioned above, student centered classrooms help prevent pruning of academic neural branches because they allow students to take control of their own educational destinies.

Research supports the old ways of questioning, discovery, and application. Terms such as inquiry, discovery, constructivist, and student - centered appear many times in research. In fact, a student - centered science classroom seems to be the most effective way to help students learn science. Student - centered classrooms allow the teacher to incorporate multiple important facets of science education into the class. Peters (2009) discusses the importance of strong teacher leadership when helping students become accustomed to student-centered methods. When correctly implemented, student-centered methods have the potential to encourage more inquiry in science classrooms. Students who took part in learner-centered science classes felt that they retained information for a longer period of time. They were invested in the gathering of that knowledge rather than having it given to them by an authority figure.

According to Marshall (2008), inquiry seems to be the foundation for becoming a competent science student. Teachers using an inquiry method of teaching will pose a question to the class that is designed to encourage critical thinking. Through a combination of research and experimentation, students gather and analyze data, prepare a written scientific report and present their findings. The inquiry method is not without its shortcomings. Often, students are uncomfortable when they do not have a set of step by step instructions to follow. They must be taught how to operate with fewer boundaries. Failure to do so often results in wasted time. A competent, well trained educator can teach his or her students how to operate effectively with in a student centered, inquiry based classroom. The key, according to Hardré, Nanny, Refai, Ling, and Slater (2010) is to engage educators in professional development "couched in authentic field experience [that] can promote knowledge and skill development for teachers." (p. 158). The goal is for participating educators to learn effective inquiry methods from these experiences, modify them, and immediately apply them to their current classroom situation. Using inquiry as a method for teaching science helps the student to become a competent critical thinker, thereby, encouraging scientific literacy rather than having the student focus on memorization. Holbrook (2010) contends that the constant expansion of scientific content makes student learning problematic. Rather, we should teach them how to extrapolate "need-to-know" scientific content so they can understand and utilize new concepts.

Inquiry has also been linked to the constructivist method of teaching. According to Cakir (2008) students who have experienced science in a student – centered, inquiry based class have been found to have

> Constructivist epistemological beliefs engaged in more active learning as well as used more meaningful strategies when learning science, whereas students having epistemological beliefs more aligned with empiricism tend to use more rote like strategies because they believe science was like a collection of correct facts. (p. 202)

It is imperative that science teachers evaluate the students' current level of understanding and identify any misconceptions they might have. This allows the instructor to develop inquiry questions designed to challenge or further develop the students' knowledge base. Through self-designed experimentation, the student becomes invested in the obtaining of knowledge that is relevant and applicable to that individual's life.

Another area that has received much discussion in science education has been the Science Technology Engineering and Math (STEM) movement. STEM calls for greater emphasis placed on the application of science and math towards technology and engineering fields. The goal is to increase student interest in careers that have roots in engineering and technology. This requires a "vigorous, integrated curriculum that creates a natural progression for learning by getting students in the mindset of being able to think about engineering as a possibility" (Rockland, Bloom, Carpinelli, Burr-Alexander, Hirsch, & Kimme, 2010, p. 59). Encouraging students to think like engineers is as simple as encouraging them to take a small electronic device apart and then reassemble it. Another example would be allowing students to learn about rollercoaster function by using pipe insulation and marbles to design miniature roller coasters.

The purpose of this literature review is to educate the reader about the science of cognitive development and how it relates to science education. The mental abilities of children and adolescents have been and will continue to be the topic of study. At this point, research agrees that learning capabilities increase as the child ages. These changes in abilities are directly correlated to the maturation of the human brain. For example, the frontal lobe is the slowest to mature. As this cerebral area is responsible for higher order thinking and reasoning functions, it stands to reason that this level of thinking would become more prevalent as the child advances through puberty.

While there is some discrepancy in the names and functionality of various learning models such as brainhood, conduit, and dualist, the foundation is the same. All researchers have either based their research on Piagetian methods or reference Piaget's operational stages. Concrete operational and formal operational stages are mentioned frequently. As an educator this is important to understand because it directly relates to the ability of students to perform certain classroom tasks. Many researchers mentioned disconnect between student cognitive ability and the cognitive demands placed upon them by the current science standards.

Research has driven the focus of this action research project to investigate the ability of students of varying ages to learn a specific science standard. With this action research project the researcher will examine student responses to an initial formative assessment probe designed to extract any current misconceptions. This will allow the researcher to determine the current cognitive constraints the students may have. It is the goal of the researcher to contribute to the current knowledge of student learning capabilities. Perhaps to even show that younger students can complete more cognitively demanding tasks than their teachers believe they are capable of. The plan for completing this research will be outlined in Chapter Three.

Methods

Introduction

The purpose of this project is to investigate the learning capabilities of students of differing ages, using inquiry methods. In the paragraphs to follow, the researcher will outline the procedures that will be used to investigate the use of inquiry to examine cognitive abilities of students of differing ages. A control group of students within grades two, five, six and nine will complete a force unit in the normal teacher driven manner. A test group within each grade will complete the unit in an inquiry, student centered manner. Pre and post assessment questions will be asked to allow the researcher to evaluate cognitive abilities of students at different ages as well as whether or not inquiry has any affect upon those abilities.

Restatement of the Problem

The purpose of this study is to investigate the learning of science students at different ages and abilities. The researcher is interested in the use of inquiry activities in a public school's elementary program. Opportunities to examine fifth grade science tests revealed test questions that did not correlate to good science teaching practices. Observation of ninth grade physical science students revealed students uncomfortable to experiment if specific directions are absent. They wait to be told how to solve a problem rather than trying to find a way to solve it themselves. At some point along their educational path, these students have been trained to follow a set of instructions to reach one specific answer. It is as if they have lost the ability to use creativity and imagination to lead their learning. These observations have caused the researcher to develop the following research question; how does the inquiry learning method affect student cognitive development at varying ages?

Research Methodology/Design Methodology

The goal of this research project is to examine the cognitive abilities of students using inquiry methods. Students from different grades will take part in a standards based lesson. One control group from each grade level will be given a pre-assessment, a formative assessment probe, and a post-assessment after students take part in their regular lesson plan. One test group from each grade will be given a pre-assessment, a formative assessment probe, and a post-assessment after taking part in their regular lesson plan that has been supplemented with an inquiry activity. Data gathered during this study will be both qualitative and quantitative. Qualitative data will be in the form of student responses gathered during the formative assessment probe and compared with in each grade level as well as across the grade levels. Quantitative data will be in the form of pre and post assessment scores that will be compared in each grade level as well as across the grade levels.

Subjects

In this section, the researcher will discuss subject selection. The researcher will outline the ages, background, and socioeconomic status of the students selected for the research study. The specific reason for selecting the research population will also be discussed in detail.

Population. Research will be conducted in a rural Minnesota community that is home to approximately 2000 people. The city boasts a new community center, hotel, clinic/hospital, library, school, nursing home/assisted living facility, a generator manufacturing plant and a grain elevator. The nursing home and manufacturing plant are the two largest employers in Springfield. Many residents also travel to nearby towns for employment. The city is also located in the heart of Minnesota farm land. Therefore, a large portion of the school's population is comprised of children from outlying farms and ranches. The school population includes 297 students in the elementary and 289 students in the high school. Residents of the community are Caucasian with a small percentage being Hispanic. This ratio applies to the school as well. The students are predominately Caucasian with a small percentage having Hispanic parentage.

Sample. The research project will require the participation of male and female students in the second, fifth, sixth, and ninth grades. Specific demographics for each grade level involved are; 45 students in the second grade with an age range of seven - eight , 41 students in grade five with an age range of 10-11, 46 students in grade six with an age range of 11-12, and 57 students in grade nine with an age range of 14-15. These students share similar motion and force based standards that will serve as the basis for the research. Instructors in these grade levels will be assisting with the teaching portion of the research project. Every student will take part in an introduction to the project and will be encouraged to participate.

Design

The design section of this chapter will specifically focus on the data collection methods used in this project. As mentioned before, both qualitative and quantitative data collection methods will be used to evaluate student progress and cognitive abilities.

Instrumentation. Two different methods will be used to evaluate student growth and ability. A formative assessment probe will be used to gain an initial insight of each student's understanding of the educational standard in question. Each student will also take a pre - assessment and a post-assessment. These scores will be compared to check for growth of knowledge about the educational standard in question.

Formative assessment probe. The section below contains information pertaining to the formative assessment probe that will be used to collect the initial data from all students. The purpose of the probe, the format that it will be given in, and any revisions that will be made will be discussed in detail.

Content. The formative assessment probe is designed to reveal understanding or misconceptions that a student may have about a particular educational standard. It is made of one question given in the form of a scenario concerning friction.

Format. The formative assessment probe consists of one specific question, usually in the form of a familiar scenario. Students are asked to predict the outcome of the scenario and then explain their answer with drawings or words. The specific probe that will be used in this research project addresses the topic of friction. It will be given to all students in the form of a card sort. Card sort probes involve giving students cards with either pictures or words. Students are then asked to divide the cards into groups of similar properties. In this case, they will be asked to determine which cards have examples of contact that would cause friction. Students are then asked to provide an explanation for why they grouped the cards as they did.

Pilot-test procedures. This probe will be piloted by consulting with the teachers of all the classes involved in the study. The researcher wants to make sure that questions asked are appropriate for all age groups. One alteration that will be made is to offer the card sort in picture form rather than words to accommodate for the primary grades and students with learning disabilities.

Pre-assessment/post-assessment. The section below contains information pertaining to the pre-assessment and post-assessment that be that will be used to collect the initial and final data from all students. The purpose of the probe, the format that it will be given in, and any revisions that will be made will be discussed in detail.

Content. The pre-assessment will be composed of five questions covering friction and the types of contact that cause friction. Pre and post-assessment questions will be the same for all age groups. However, the way the question is posed will be altered to make them more appropriate for the second grade students.

Format. Students will take the pre-assessment prior to the formative assessment probe. At the completion of the unit, students will take the post-assessment, which will be exactly the same as the pre-assessment. The assessments will be composed of five questions pertaining to the topic of friction and contact between surfaces. Alterations will be made to the second grade assessments. The goal is to assess the same content in a more age appropriate way, such as converting a multiple choice wording to more simple terms.

Pilot-test procedure. The pre and post-assessments will be piloted by consulting with the teachers of all the classes involved in the study. The researcher wants to make sure that questions asked are appropriate for all age groups.

Procedures

This section of the methodology will specifically explain how the formative assessment probe and the pre/post assessments will be used to gather data. Instrument implementation and importance will be examined in this section.

Data collection procedures. Student learning and cognitive abilities of students in grades two, five, six, and nine will be examined. Each grade has two sections. One section will serve as the control group and the other section will serve as the test group. The test groups will be given a pre-assessment about friction. They will then be given a formative assessment probe to evaluate their current level of knowledge on the concept of how contact relates to friction. An inquiry lesson will be added to the normal teaching methods already used by the classroom teacher. A post-assessment will be administered at the completion of the unit. The control group will participate in the pre-assessment, formative assessment probe and the normal teaching methods of the classroom teacher without the inquiry lesson. They will take the same post-assessment at the conclusion of the unit. The formative assessment probe, pre-assessment, and post-assessment will assess the same content for all age groups. Pre and post-assessment will be duplicates of each other.

Help from the teachers of each grade level will be paramount. The researcher will design and provide the formative assessment probe, the pre and post-assessments, and the inquiry activity. The teachers of each grade level will administer the formative assessment probe and the pre and post-assessments. The classroom teachers will also conduct their normal lesson plans for the chosen academic standard. The inquiry activity will be implemented, immediately following the formative assessment probe, for the test group. All data collection will take place in each teacher's classroom, by the classroom teacher. The researcher will gather all materials from the classroom teacher upon completion by the students. Both the elementary principal and the high school principal will give permission for this project to take place. Data collection will continue until all grade levels involved have completed the required material. It is the researcher's goal to have data collection completed by the end of the second quarter of instruction.

Data analysis procedures. After each instrument has been completed, the researcher will collect the data and organize it for evaluation. The formative assessment probe will be analyzed in two ways; the answer to the given scenario and the explanation given for each answer. This information will be compared amongst students in the same grade level as well as across grade levels. The researcher is interested in examining how the answers vary in degree of complexity between the different grade levels. The student answers to the post-assessment questions will be compared to the pre-assessment answers to check for growth of understanding.

Summary

The researcher will use pre and post-assessment, a formative assessment probe, and an inquiry activity to measure student understanding and ability to manipulate abstract concepts. Research will be taken from grades two, five, six, and nine and results of all assessments will be compared within grade levels as well as across grade levels. Data and significant outcomes will be discussed and diagramed in Chapter Four.

Results

Introduction

In this chapter, the researcher will examine the data collected during the study. This chapter will include graphs and narratives that outline and describe the instruments used to collect data that is important to the study.

Findings and Results

Results of the pre-test, the formative assessment probe, and of the post-test will be examined. Data was collected on each of these mechanisms for physics students, ninth grade physical science students, sixth, fifth and second grade elementary students. The researcher will examine the data in two different ways. Horizontal examination of data will allow the researcher to examine data within a grade level. Vertical examination of data will allow the researcher to compare data across grade levels. Data for the formative assessment probe will be evaluated first, with comparisons of pre and post-assessment data to follow. All data are in the form of percentages. It was felt that this would be the most accurate way to depict results for different classes with different numbers of students.

Formative assessment probe. The data collected from the formative assessment probe were broken down into percentages of each class that chose a particular answer. The probe was divided into four questions that focused on a rocket. The students were given a set of parameters for the rocket and asked to choose the design that would best meet the design requirements. A copy of the formative assessment probe is included in Appendix D. The parameters set required a rocket that could turn quickly in any direction. The pictures of four rockets were given to the students. The rockets had different wing components as well as different engine components. Rocket C was the rocket that best met the parameter requirements given in the probe because it had booster engines surrounding it on all exterior walls. To correctly answer the probe, the students had to have an understanding of Newton's 3rd Law of Motion which states; "For every action, there is an equal and opposite reaction." Data collected from the formative assessment probe may be seen in Figure 1. The results of the probe for the physical science students show that 20% of the students in the test group chose answer A, 26% chose answer B, 43% chose answer C and 11% chose answer D. The results for the control group of physical science students are as follows; A, 5%, B, 57%, C, 10%, and D, 29%. In the sixth grade, 14% of the test group chose A, 23% chose B, 36% chose C, and 18% chose D. 5% of the control group chose A, 62% chose B, 19% chose C, and 14% chose D. The fifth grade results show that 10% of the test group liked rocket A, 50% of them liked rocket B, 15% liked rocket C, and 25% chose rocket D. In the control group, 15% chose rocket A, 50% chose rocked B, 15% chose rocket C, and 20% chose rocket D. In the second grade test group, 23% chose A, 41% chose B, 18% chose C, and 18% chose D. In the control group, 9% chose A, 78% chose B, 9% chose C, and 4% chose D.

When the researcher looked at the results in broad spectrum, it became obvious that rocket B was the overwhelming favorite. Rocket B had a long body with a cone shaped nose. It had one engine at its base and it had large, triangular shaped wings on each side of the body. This choice indicates that students believe large wings are important for turning ability. This information helped the researcher determine which inquiry activity would best suit the students involved in the study.

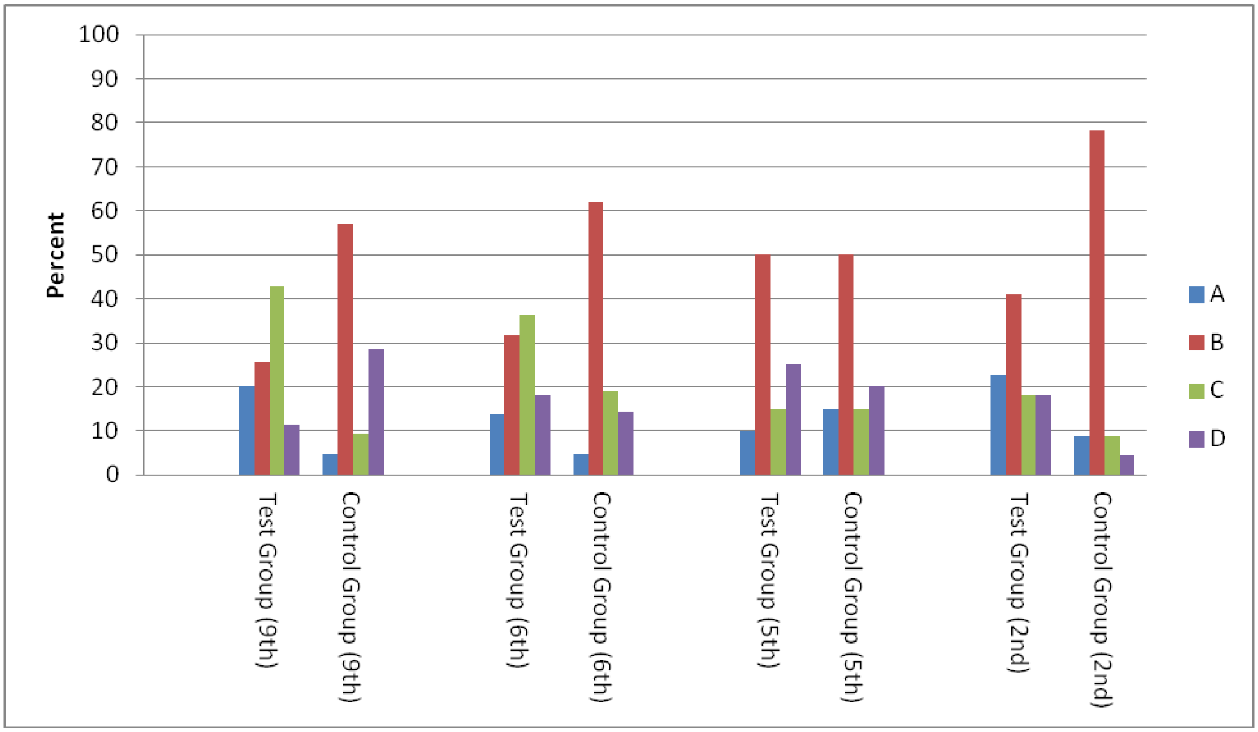


Figure 1. Formative assessment probe results for all grades studied.

Pre-test and post-test. The researcher will next examine the results of the pre-assessment and post-assessment simultaneously. Both assessments are identical and included three questions. The first question asked students to give an example of a force. The second questions asked students to describe how forces can cause motion to change. The third question gave the students three pictures to examine. In each picture, a "strong man" is tied to a different combination of horses and or trees. The strong man is content in all but the last picture when he is pulled on one side by two horses and tied to a tree on the opposite side. In that picture, he says "Ouch!" The students were asked to explain why the strong man says ouch in the last picture but is apparently fine in the first two.

The questions included on the pre and post-assessment increase in difficulty and their demand for student understanding about forces. The first question is cognitively simple as it asked for an example of a force. The second question increases in difficulty because it asked for a relationship between force and motion to be explained. The third question requires students to translate Newton's 3rd Law of Motion to the scenario of the strong man. Correctly answering this question would show cognitive growth in the area of relating equal and opposite forces to a potential real life situation. Copies of the pre and post assessment may be found in Appendix A, and Appendix D.

Data for the physical science test group students are shown in Figure 2, data for the control group are shown in Figure 3. Side by side comparison of the pre and post-assessment data for the physical science control group shows a 14% increase in correct responses for question 1, a 54% increase in correct responses for question 2 and a 31% increase for question 3. Although question 3 showed a significant increase in correct responses, the overall percentage was still only 37% of the class who answered the strong man question correctly. The results for the control group showed a decrease of 14% in the number of correct answers to question 1, an 11% increase in correct responses for question 2 and no change in the number of correct responses for question 3.

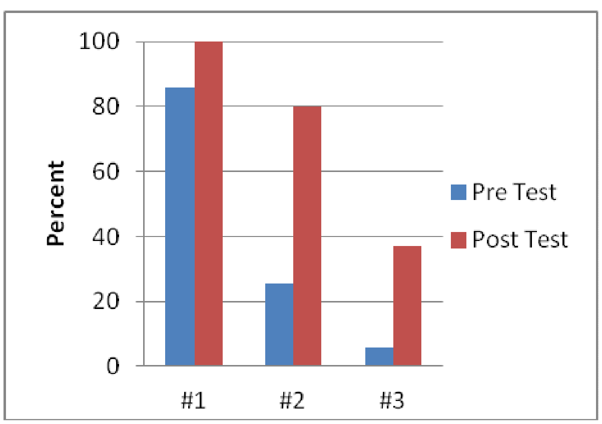


Figure 2. Physical science test group.

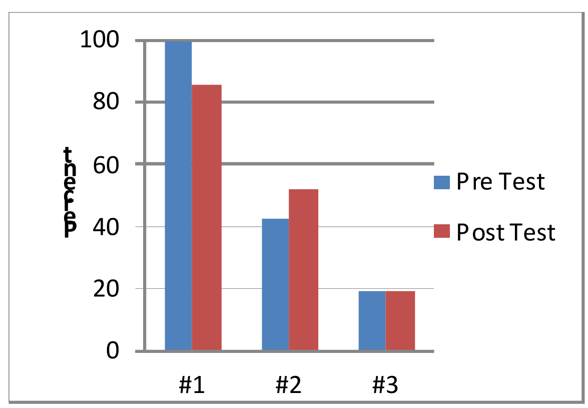


Figure 3. Physical science control group.

Data for the sixth grade test grade students are shown in Figure 4. Data for the control group of sixth graders are shown in Figure 5. In the test group, a 9% increase is shown between the pre and post-test question 1. This small increase is because 91% of the students answered correctly on the pre-test and 100% answered correctly on the post test. The sixth grade test group also showed a 59% increase in correct responses for question 2 and an 18% increase in correct responses for question 3. The control group of sixth graders showed a 5% drop for question 1. However, they showed an increase in correct responses for questions 2 and 3 of 43% and 24% respectively.

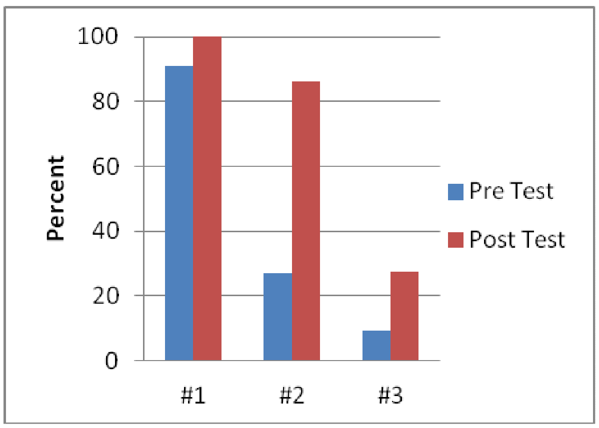


Figure 4. Sixth grade test group.

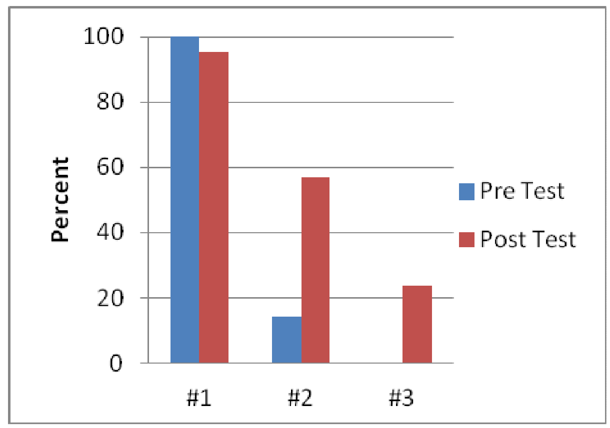


Figure 5. Sixth grade control group.

Data for the fifth grade test group may be found in Figure 6 and the data for the control group can be found in Figure 7. The fifth grade students in the test group continued the trend of growth. These students showed a 30% increase in correct responses to question 1, a 35% increase in correct responses to question 2, and a small 10% increase in correct responses to question 3. The control group of students in the fifth grade continued the trend of a dropping percentage of correct responses for question 1. They showed a 10% decrease in correct responses. They did show improvements in questions 2 and 3 with 50% and 5% increases respectively.

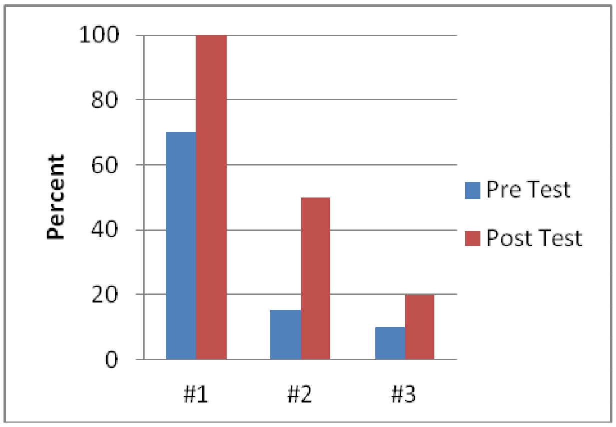


Figure 6. Fifth grade test group.

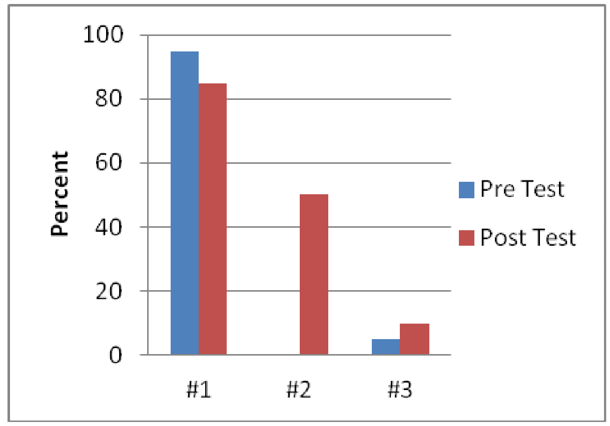


Figure 7. Fifth grade control group.

Data for the test group of second graders are shown in Figure 8. This group of students showed great growth on all three questions. Their correct answers to question 1 improved by 59%, question 2 correct answers improved by 36%, and question 3 correct answers improved by 26%. Data for the control group of second graders are shown in Figure 9. These students showed a 66% improvement in correct responses to question 1 and a 13% improvement in correct responses to question 2. This group showed no change to their responses to questions 3; 4% answered correctly on both the pre and post-assessment.

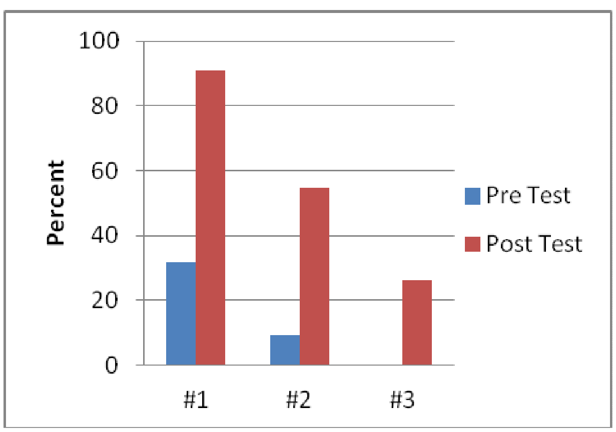


Figure 8. Second grade test group.

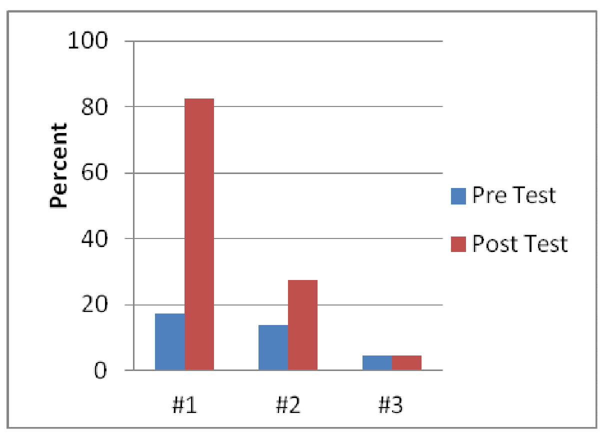
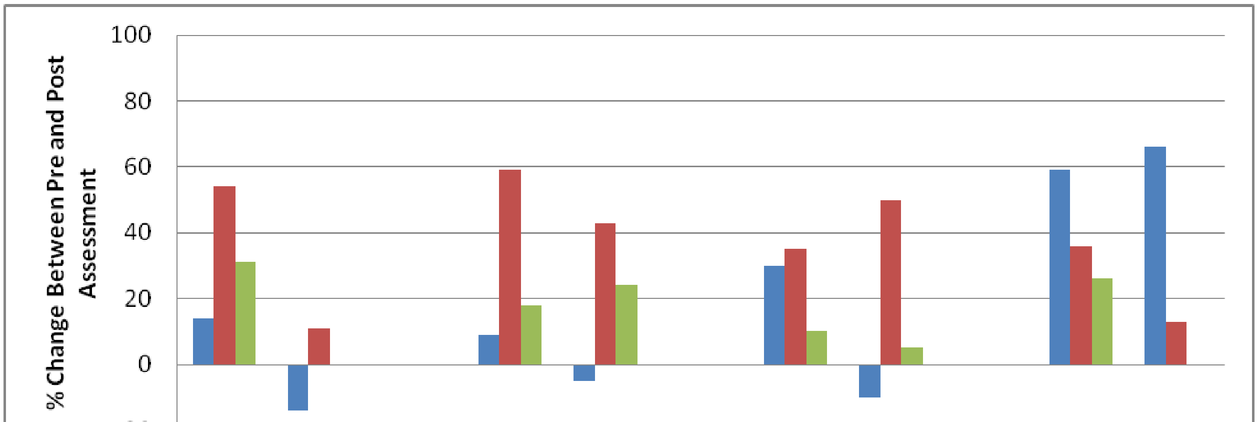


Figure 9. Second grade control group.

Growth comparison between classes. A vertical comparison of growth between all grade levels involved in the study is shown in Figure 10. When looking at a comparison of growth vertically, it is evident that the second grade students began their force unit with a smaller base knowledge about the topic than the older students in the study. Therefore, one could argue that they had the most room for growth. Both the test and control groups did, in fact, show the most growth in question 1. The test group of second graders was also very comparable to the fifth and sixth graders in their ability to relate force to motion, as stressed in question two. The test group of second graders also outperformed both groups of fifth and sixth graders in their ability to relate Newton's 3rd Law of Motion to the strong man scenario described in question 3.

Small growth percentages for the ninth grade test group and the sixth grade test group are due to the fact that both groups started out with a strong knowledge of what forces are. Both of these groups reached 100% understanding on the post test. The 5th grade test group also reached 100% understanding on question 1 but showed a greater improvement because they started with 70% of the group able to describe a force. One area of concern is the trend noticed when looking at the control groups for ninth, sixth, and fifth grades. Why do their scores for question 1 drop?



	Test (9th)	Control (9th)		Test (6th)	Control (6th)		Test (5th)	Control (5th)		Test (2nd)	Control (2nd)
#1	14	-14		9	-5		30	-10		59	66
#2	54	11		59	43		35	50		36	13
#3	31	0		18	24		10	5		26	0

Figure 10. Growth comparison between grade levels.

In this chapter, the results and findings were presented. The data gathered from the formative assessment probe showed that a large percentage of the study population chose rocket B over all others. This exposed a student misconception that change in motion of a rocket was controlled by the wings. It also prompted the researcher to use the Pop Rocket inquiry activity as the variable of study between the test groups and the control groups of students. Comparison of data between the pre-test and the post-test showed that all test groups improved, at least minimally, on their ability to correctly answer all three questions. The results of the control group were not all positive, as the control groups in the ninth, sixth, and fifth grades showed a decrease in their ability to correctly identify a force.

In Chapter Five, the researcher will look more closely at these results. Implications as they relate to science teaching in both elementary and high school science classes will be discussed as well as recommendations for future research.

Discussion

Introduction

In this chapter I will further examine the findings of my research and relate the use of inquiry activities to student achievement, not only in the high school, but also in the elementary classroom. I will compare my findings to corresponding research about cognitive abilities of students and discus how this research impacts the science education of our students.

Summary of Study

Through the initial research phase, I learned a great deal about the cognitive ability of the students I teach. I learned that the best way to truly learn about science is to cause students to experience disequilibrium. This occurs when new information does not correspond with their current knowledge. The process of integrating the old and new knowledge is a key step to true learning. I also learned that the ability to accurately assess, integrate, and apply new knowledge increases with age, as the cognitive ability of a student matures. I wondered if this affected a student's ability to learn from an inquiry based science activity.

Upon completion of my research I designed an investigation that would allow me to examine that very question. I examined Minnesota state science standards and determined to focus my study on classes that shared a common science standard pertaining to force. Upon gaining approval from administrators and the teachers whose classes I would be studying, I prepared a pre and post-test and a formative assessment probe. The formative assessment probe allowed me to evaluate the current level of knowledge possessed by the students, or to uncover any current misconceptions they had. One control group from each grade tested received regular instruction. Instruction for one test group from each grade was varied with the addition of the pop rocket inquiry activity. Results have been graphed and documented in the previous chapter.

I will now discus my findings, trends that I noticed, and the conclusions I was able to draw from my data.

Summary of the Findings and Conclusions

When I examined the data collected from the formative assessment probe, instantly learned that many students have a misconception about the ability of wings to control the motion of an object in flight. The rocket of choice for many students was rocket B. This rocket had large triangular shaped wings on either side of the body and one booster engine at its base. Neither rocket A nor rocket D had wings. They did have multiple engines, but all the engines were at the bottom of the body. Rocket C was shaped in a pentagon design and it had engines on each of its five faces. This was the only rocket that truly met the requirement of being able to turn quickly. Students who chose this answer showed that they had an understanding for how engine thrust directed the rocket's change in motion. Many students were not able to describe their reasoning using correct scientific terms but they were able to accurately describe the thought process behind their choice.

From this probe I was able to determine that the pop rocket inquiry activity would be good for the test group of students to participate in. The activity allowed the students to make rockets, using film canisters as the rocket body. The "rocket fuel" was produced by mixing an effervescent antacid tablet with water trapped in the canister. As the reaction between the antacid and the water progressed, carbon dioxide gas built up in the canister. When "maximum capacity" was reached inside the canister, the cap, which was placed down against the ground, would blow off, projecting the rocket upward into the air. This was a classic demonstration of Newton's 3rd Law of Motion which states "for every action, there is an equal and opposite reaction." Students were given time to experiment with their rocket's body, wings, and rocket fuel components. Many tried to start with a great amount of water in their film canister. By the end of the activity, even the youngest students figured out that filling the canister with water limited the amount of room the gas had to build up in. Less gas resulted in a rocket that did not fly as far because there was less launch force.

Pre-test data was used to gain a baseline understanding of all students' knowledge of forces. The students were asked to give an example of a force in question one. All students, except the second grade students, showed a good ability to answer this question. However, I found that "push or pull" was the most common answer, when students were faced with the question "what is a force?" I was hoping to find a greater variety in answers than the standard book definition. Students were asked to describe how motion was changed by forces in the second question. Finally they were asked to describe a scenario that was pictured. To correctly answer the second question, they had to have a good understanding of the relationship between motion and forces. To correctly analyze the third question, they needed to be able to apply Newton's 3rd Law to the pictures. The number of correct reposes to these questions was significantly lower. These questions were more cognitively demanding because they required the students be able to relate concepts and situations to one another. This ability is one of the last to mature in an adolescent brain. Sousa (2006) states that the frontal lobes are responsible for planning, rationality, higher order thinking, processing, and emotional control. The frontal lobe is also the lobe that takes the longest to fully mature, sometimes, as long as early adulthood. The temporal lobes specialize in recognition of objects, music, and faces. The occipital lobes process visual stimuli while the parietal lobes process calculations, special awareness and other types of recognition. Because of this research, I was anticipating these results on the pre-test.

The post-test revealed some surprising results. The post-test was identical to the pre-test. Both control and test groups in all grades were able to complete the first question with at least 83% understanding. I was both pleased with and anticipating this result because of the cognitive complexity of this question. There was nothing relational about this question so even the second graders were able to correctly respond. One alarming trend I noticed was that the control groups in the ninth grade physical science, sixth grade, and fifth grade showed a decline in their ability to answer this question. As a class, they all showed a strong understanding of force examples because their completion percentage was 86%, 95%, and 85% respectively. Still, the drop in completion deserves consideration.

When I examined responses to question two, I was pleased to see that the test groups from ninth, sixth, and second grade showed a greater increase in their ability to correctly relate motion to force than the control groups in those grades. The fifth grade test group did not show greater growth than their control group counterparts because they started with a higher baseline of understanding. Both groups ended with 50% of the group correctly relating motion to force. This trend is also true of question three. Overall, the number of correct responses to question three was significantly lower than the previous two questions. I feel this is because this question required more cognitive ability that its two predecessors. All students in all test groups showed growth in their ability to answer this question.

In all cases, the total percentage of students who showed understanding in the test groups was greater than those showing understanding in the control groups. I feel that this data shows a positive relationship between inquiry and the ability of students to use that experience to build knowledge. The students who were able to participate in the pop rocket inquiry activity showed greater growth than those who did not have that opportunity. I feel this was because the activity allowed the students the freedom to explore how changes in the water and antacid variables affected the rockets ability to fly. The great surprise of the study was the group of second graders. When I looked specifically at their data, I noticed the test group's data followed the cognitive research to a point. They were strong in their ability to identify forces. Their data continued to follow the trend by decreasing slightly from questions one to three as the cognitive complexity of the question increased. However, they also defied research.

According to Endler and Bond (2007), concrete operational thinking primarily focuses on identifying words, objects and symbols. Students operating at the concrete operational stage would classify objects as heavy and light in a density experiment. Students who have advanced to the formal operational thinking stage have the ability to expand upon their knowledge by asking questions, forming hypotheses, exploring their implications and testing their thoughts for validity. These students have the ability to make connections between concepts that they would not have been able to make at a younger age.

When answering the most difficult question, number three, the test group of second graders outperformed every group tested except the test group of ninth and sixth grade students. They came within one percentage point of the sixth grade test group. In the second grade test group, 26% were able to correctly explain why the strong man said "Ouch!" I contend second grade students are more creative and less inhibited than older students. They may not possess the ability to use the correct scientific terminology when answering the more cognitively demanding questions, but they are certainly able to rationalize discrepant events in their own terms. I cannot help but feel as though we are missing out on a tremendous opportunity to foster creativity and inquisitiveness in our students.

Recommendations

This next section will outline recommendations based upon my research. I will discuss recommendations for its use in the classroom as well as recommendations for future research.

Recommendations for practice. As I mentioned above, I feel as if we are depriving our students of great opportunities to learn. When I asked the second grade teachers to participate in my study, they became apprehensive about the inquiry activity. Inquiry demands that the teacher give up control of the classroom. I admit that the thought of letting 22 second graders run free in a classroom is daunting. I offered to have my 11 physics students come to the second grade classroom to help. I talked with my physics students about the goal of the investigation and about how I would like them to act as helpers to the second grade students but to not direct their actions. All of the work needed to be an authentic representation of second grade work. Each physics student was partnered with two second graders. They helped the students tape rockets, add the water and antacid tablet to the "fuel cell", and measure the height that the rocket traveled. The physics students taught them how to use stopwatches to measure the time the rockets were in the air and they taught them how to use the electric balances to measure the mass of their rockets. I feel strongly that incorporating more inquiry activities into our elementary science curriculum will greatly improve our students' ability to solve practical problems through questioning and experimentation.

I also feel that data supports the implementation of inquiry, not only in the elementary but also in high school science classes. It is evident that the students in all test groups showed greater improvement in their understanding of force concepts than those in the control groups. I believe that the inquiry activity played a key role in this improvement. I recommend that schools provide their elementary and high school science teachers staff development that focuses on implementing inquiry opportunities into a school wide science curriculum. The training can help teachers learn how to incorporate inquiry activities into their curriculum. It can also help them feel more comfortable in this type of student centered environment.

Recommendations for future research. While I am happy with the results of this study, I feel strongly that it is inadequate. There were a variety of problems with this study; primarily the fact that each grade level of students was taught by a different teacher. This resulted in a great variety of inconsistencies in teaching methods as well as inconsistencies in material taught during each class' force unit. I was able to meet with all of my cooperating teachers to discuss goals and expectations but I could not account for individual variables in teaching styles. I would like to see this study expanded. I would like to look more closely at the younger elementary students; particularly kindergarten through third grade. Were the results I was able to show with the second grade true or incidental? Also, I would be interested to discover the reason for the drop in understanding displayed by the control groups of ninth, sixth, and fifth graders. This drop occurred on question one of the post test. This question was of the most basic variety, so why did the students not improve or remain constant?

Implications

During this study, I learned that student abilities that have been left untapped. In public schools, our elementary students are the most uninhibited and unafraid of making mistakes. As our students progress through their years of public school, they are unintentionally trained to look for the right answer and to fear making mistakes. The heart of inquiry is to use mistakes as an avenue for learning. By the time ninth grade students reach my classroom, they want me to tell them the best method to find one correct answer. I want them to question and explore different possible solutions. They are afraid to make a mistake because it will reflect poorly on their grade. I want them to make mistakes and then learn from them. Inquiry provides students with this opportunity because they are continually evaluating their work, making changes, and then re-testing. They simultaneously apply engineering and science concepts.

I hope to use these findings to encourage my school's administration and science teachers to slowly make the transition from science lectures and structured investigations to more inquiry and student-centered methods. I am excited to see the improvement that our students show in their abilities to problem solve in all classes, not just those taught by our science teachers.

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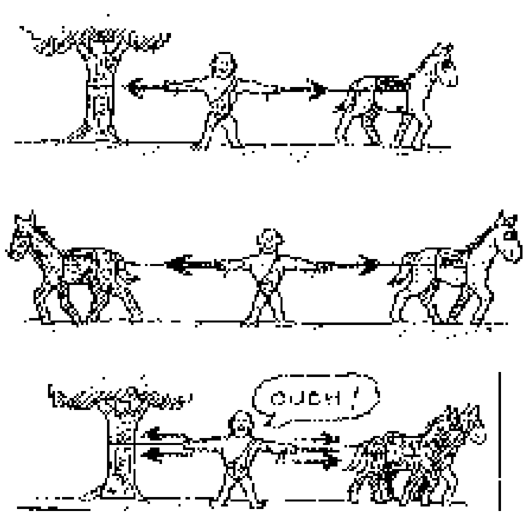
Appendix A

Force: Pre – Test

1. Give an example of a force.

2. How does a force cause motion to change?

3. Look at the pictures of the strong man. Explain what is happening in each picture. Why does he say "OUCH!" in the last picture?



Appendix B

Formative Assessment Probe

Forces and Newton's Laws

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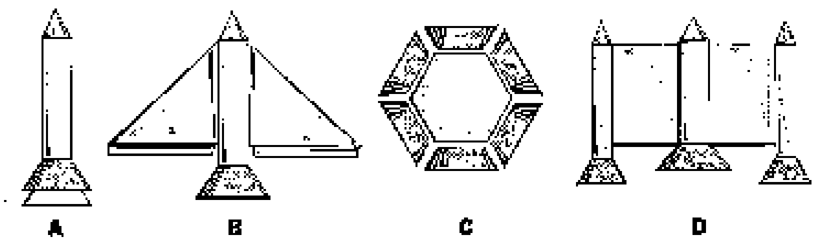
Spaceships

You are part of a team that has been asked to choose a design for a plane for outer space. It is very important that the plane be able to turn quickly. The engines that are attached to each plane are shown with this symbol:

Circle the design that will BEST allow the plane to turn quickly in space.



Explain your thinking. Describe the reasoning that helped you decide which design to select.

Uncovering Student Ideas in Physical Science 103

Appendix C

Pop Rockets - Student Data Sheet

1. This is what my rocket looks like: (draw your rocket)

2. My rocket is this tall. _____________ Inches

3. My rocket weighs this much. _____________ Grams

4. I used this much water. (circle one) 1/3 full ½ full 2/3 full

5. At the launch watch how high your rocket goes. Then record the height.

   My rocket went this high. _____________Feet

6. Find a classmate whose rocket went higher than yours. **How was their design different than yours?**

   Rocket length _____________ Inches

   Rocket weight_____________ Grams

   Launch Height_____________Feet

7. Find a classmate whose rocket did not go as high as yours. **How was their design different that yours?**

   Rocket length _____________ Inches

   Rocket weight_____________ Grams

   Launch Height_____________Feet

Pop Rockets!!

Student Data Sheet

Newton's 3rd Law of Motion says *"for every action, there is an equal and opposite reaction."*

1. What was the action that caused the rocket to move? How to you know?

2. What was the reaction of the rocket? How do you know?

3. Name one thing you could change in the experiment that might make the rocket move differently. How will it change the rocket's movement?

Appendix D

Force: Post – Test

1. Give an example of a force.

2. How does a force cause motion to change?

3. Look at the pictures of the strong man. Explain what is happening in each picture. Why does he say "OUCH!" in the last picture?