Using time-lapse and stroboscopic photography to enhance student understanding of plant growth, structure, and pollination: an inquiry-based study

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USING TIME-LAPSE AND STROBOSCOPIC PHOTOGRAPHY TO ENHANCE STUDENT UNDERSTANDING OF PLANT GROWTH, STRUCTURE, AND POLLINATION: AN INQUIRY-BASED STUDY

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

In

The Department of Educational Theory, Policy, & Practice

By

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May 2007
DEDICATION
To my mother Elizabeth N. Perkins

and

The memory of my mother-in-law, Josie Carreca.
ACKNOWLEDGEMENTS

The accomplishment of something significant is rarely the work of an individual. I would have never reached this point without the undying support of family, friends, and mentors.

I could never adequately express my appreciation to my wife Mary Ann, who has always been there to support me in this endeavor. It would have been impossible without her.

A special thanks to my children, grandchildren, and mother for their support. A special thank you goes out to Brandi and Daniel for being my test subjects when I needed them and my sister Betty for her help in constructing the black room.

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ABSTRACT

This study was designed to evaluate the effects of allowing students to generate their own images in a science class as opposed to using pre-existing images. The participants in the study were 7th grade science students enrolled in a small, rural, Louisiana school. A mixed methods design was used so that call available data was collected and analyzed. The lessons used in the study were based on plant structure, growth, and propagation which fit into the mandated 7th grade science curriculum. The students were involved in the taking of still, time-lapse, and stroboscopic images throughout the study. Although an analysis of the quantitative data showed a significant increase in the test scores for both the control and treatment groups but no significant difference when they were compared to each other, the results of the qualitative study revealed many important findings about the value of the image-based learning interventions for enhancing students’ inquiry skills, on-task behavior, and observable satisfaction with studying science.
INTRODUCTION

Historical Aspects of Scientific Images

“Humans have made pictures for at least thirty thousand years” (Pinker, 1997, p. 215). From the age of caveman to the technologically sophisticated age of digital cameras and high speed computers, images have played important roles in man’s recording of nature (Robin, 1992).

Carbon 14 dating has shown that the cave drawings found in the Chauvet Caves of France were made approximately 30,000 years ago (Chauvet, Brunale, Deschamps, & Hillaire, 1996). These artifacts, crude by our present day standards, are the earliest known examples of engravings, paintings, drawings, and sculptures used to record observations. There are over 600 known examples of cave or rock art in France, Spain, Italy, Portugal, Germany, and the Balkans (Johnson, 2005).

Although the level of sophistication used to create observational recordings has increased with technological advances, the purpose remains the same; the recording of an event or perception for future recall. As technology improved, freehand sketches were supplemented with tracings made with the aid of a camera obscura, a technique which was developed over 2000 years ago (Lubell, 2004). The camera obscura used a darkened room much like the case of a box camera. Light reflected off an image would pass through an opening in one wall and was reproduced inverted on the opposite wall of the room. This would be analogous to reflected light passing through a box camera’s lens and being projected on the opposite side of the box. Instead of the image striking light-sensitive film on the opposite wall and recording the image, the image would be projected on a medium on which an artist would trace the projected image (Leggat, 1995; Museum of Contemporary Photography, 1998; Newhall, 1964). Since this process still
required partial interpretation by the artist the resulting image was questionable to some scientists.

Fox Talbot and Louis Daguerre further changed the method of recording observations with their pioneer work in photographic imaging (Greenspun, 2000; Leggat, 1995; Museum of Contemporary Photography, 1998; Robin, 1992). The evolution of imaging has now reached the electronic stage with digital imaging providing the latest means of capturing and storing observations.

Images have been integral components of scientific investigations and documentation by providing time-specific artifacts of phenomenological activities. The scientific use of images falls into six distinct categories: observation, induction, methodology, self-illustrating phenomena, classification, and conceptualization (Robin, 1992).

Historically scientists have used images as a means of recording their observations: Johannes Hevelius’ Map of the Moon 1647 (Robin, 1992), Erasmus Darwin’s Vallisneria Spiralis 1789 (Robin, 1992), and Sir Joseph Hooker’s Rhododendron Dalhousie 1848 (Musgrave, Gardner, & Musgrave, 1998). When Sir Joseph Banks booked passage with Captain Cook aboard the Endeavor in 1768 to study flora and fauna on the South Sea Islands, he included three illustrators in his party (Musgrave et al., 1998). By that time in history, images were not only a means of documenting what had been observed but also provided a means of preserving what had been seen for future analysis by both the observer and other interested individuals.

**Multiple Images**

When an observed phenomenon changes over time, a single image is not sufficient to accurately record the phenomenon. For centuries scientists have utilized what Edward R. Tufte calls small multiples (Tufte, 1983, 1990, 1997) to visually record an event which produces or
involves changes over time. Galileo Galilei’s *Six Phases of the Moon* (Robin, 1992), Eduard Strasburger’s *Division of the Cell Nucleus* (Robin, 1992) Jorge J. Yunis and Om Prakash’s *The Origin of Man: A Chromosomal Picture Legacy* (Tufte, 1983) Christian Huygens’ *Systema Saturium* (Tufte, 1990), and Eadweard Muybridge’s *Jumping Over Boy’s Back* (Leapfrog) (Tufte, 1997) are examples of using small multiples to visually record and communicate a phenomena whose understanding is dependant upon a sequence of events.

When Eduard Strasburger first observed how plant cells divide after fertilization, he used 62 images to record and show his observations to the scientific community (Robin, 2002). It would have been impossible to show the multiple stages of cell division and to transfer this new understanding of plant cell division to others without the use of small multiples.

The use of sequential imaging can be advantageous to the study of both physical and biological phenomena. Claude Nurdisany and Marie Perennou’s book, *The Metamorphosis of Flowers* (Nuridsany & Perennou, 1998), utilized a series of images to show the unique sequencing of the flowering head of a teasel, the development of a head of round head garlic, and the transformation of a field of dandelions from a sea of yellow flowers to an aerodynamic ballet of tiny white parachutes transporting seeds to their new homes. A single image could not show the unique wave of flowers starting at the waist of the capitule and diverging in two distinct rings as the corollas blossom and fall to the ground, nor could it show the opening and closing of the bracts and the transformations that take place within the plant.

Harold Edgerton used a sequence of images to show a bullet as it approached, entered, and exited a common light bulb in “Death of a Light Bulb” (Jussim & Kayafas, 2000). The physical relationships of time, space, and effect would be lost in his experiment without the use
of multiple images. In both of the above examples the recording of a single moment would not transmit the true nature of the phenomena.

**Technological Changes in Imaging**

The methods used to capture and store scientific images of naturally occurring and man-made phenomena have changed with the development of new technology. Although hand sketches of observed phenomena are still made by researchers, students, and artists, these sketches are now augmented or replaced entirely by images taken with film or digital cameras (Wright & Dahl, 1995). The results of these changes are illustrated by comparing the sketches of the moon’s phases made by Galileo Galilei in the early 17th century (Robin, 1992), Wilhelm and Friedrich Langenheim’s “Seven Daguerreotypes Showing Eclipse of the Sun” in the late 19th century (Marien, 2002), and those taken for NASA by the Jet Propulsion Laboratory/California Institute for Technology in the late 20th century (Luhr, 2003). While many scientists viewed, with suspicion, images that depended all or in part on the human hand, the new technologies allowed for more accurate descriptions. In 1839 William Henry Fox Talbot published a treatise, *Some Account of the Art of Photogenic Drawing-The Purpose by Which Natural Objects May Be Made to Delineate Themselves without the Aid of the Artist’s Pencil* (Davenport, 1991). This document changed the way that many viewed the integrity of images (Marien, 2002).

The need for image production that accurately recorded events with extremely high or low rates of change, that met the integrity standards of scientists, and that provided visual proof of phenomenological changes over time provided incentives for such men as John Ott and Harold Edgerton to develop techniques and equipment that would forever change scientific imaging (Belloli, 1990; Jussim & Kayafas, 2000; Marien, 2002; Ott, 1958). Ott’s work allowed
us to watch the dynamic nature of a growing plant while Edgerton’s work enabled us to see the initial millisecond of a bomb exploding from a static prospective.

**Stroboscopic Photography**

With the advent of photography, not only was the efficacy of scientific imaging greatly enhanced but the observable time required before and during the recording of a specific change was drastically reduced. High speed stroboscopic photography, pioneered by Edgerton in the early 20th century (Jussim & Kayafas, 2000), provided techniques and mechanisms to capture images of events whose rates of change were too fast for the human eye to record and for the mind to accurately process. By utilizing a combination of high intensity light flashes with durations as little as 1/100,000th of a second, high speed motion picture cameras, and revolutionary triggering devices, Edgerton was able to produce images of phenomenological events never before seen. The time required to capture an event time was reduced to the point that ultra fast phenomena such as the initial microseconds of the detonation of an atom bomb (Jussim & Kayafas, 2000) and a drop of milk splashing in a saucer of milk (Jussim & Kayafas, 2000; Newhall, 1964) could be frozen in time on film. Edgerton’s techniques and equipment enabled scientists to see and analyze phenomenological changes that were previously seen only in the mind of the theorist. His work revolutionized the use of imagery in scientific investigations. High speed stroboscopic imaging allowed scientists to see what was once unseen and re-evaluate the phenomena under investigation for a deeper and more accurate understanding.

**Motion Pictures**

“Magic lanterns” were precursors to motion pictures. In 1420 Giovanni da Fontana suggested painting demonic shapes on the window of a lantern to cast shadows that would
frighten people. In the 1600’s, Athanasius Kircher refined this process creating the first magic lantern (Naughton, 2001) that produced the impression of movement. Various methods were used in conjunction with magic lanterns to make the images appear to move. One such method was to take two sequential images and quickly move the slide between the images (Kaske, 2001). During the 19th century many devices were invented that used a series of still images on a spinning cylinder or disk to produce the visual sensation of motion. Among these inventions were the phenakistiscope, zoopraxiscope, thaumatrope, zoetrope, and praxinoscope. “The Zoopraxiscope, developed by photographer Eadweard Muybridge in 1879 … projected a series of images in successive phases of movement. These images were obtained through the use of multiple cameras. The invention, in the Edison laboratories, of a camera capable of recording successive images in a single camera was a more practical, cost-effective breakthrough that influenced all subsequent motion picture devices” (Library of Congress, Motion Picture, Broadcasting, and Recorded Sound Division, 1999).

A motion picture is actually a sequence of still images taken at uniform time intervals which are projected on a viewing screen in a manner that allows the viewer to visually experience the fluid motion of the captured events. The individual images or frames are projected on a screen at a rate of 24 frames per second which produces the sensation of continuous motion. This is due to a combination of film speed and persistence of vision. Persistence of vision is the retention of an image by a human for a short period of time after the image is gone and is aided in the movie theater by the darkness of the room and the brightness of the image on the screen (ThinkQuest, 2005).
Slow Motion

Slow motion imaging is the process of creating visual time expansion by capturing images at a high rate of speed and projecting them at a slower rate. Slow motion imaging is not new and was used in the late 19th century when Eadweard Muybridge used a series of 24 cameras to capture the motion of a horse running and Etienne Jules Marey developed a slow motion camera with the capacity of taking 700 images per second (Leggat, 1995). The use of slow motion imaging allows viewers to see details occurring at high speeds that otherwise would go unnoticed. Edgerton led this advancement and along with his colleagues Kenneth Germeshhausan and Hebert Grier, collaborated with Pete Smith of MGM studios to produce the Oscar winning film *Quicker than a Wink*. This film used slow motion to show viewers “heretofore unseeable details” of everyday events (Jussim & Kayafas, 2000, p.7).

Slow motion is more than a media that can be used to entertain audiences with spectacular footage of common occurrences in an expanded time frame. For over 100 years slow motion imaging has been used by investigators to see and analyze events that occur at rates too fast for the human eye and mind to process. In 1952, Harold Edgerton captured the first microseconds of an atomic bomb being detonated in a 1/100,000,000 of-a-second exposure (Jussim & Kayfas, 2000). High speed imaging allows scientists and engineers to study machinery in motion, develop identification devices to catch speeding drivers, study the aerodynamics of supersonic flight, and study the behavior and motion of many living organisms.

Time-Lapse Photography

The existence of phenomenological changes that occur too fast for the human eye to capture for processing is paralleled by phenomenological changes that occur at a rate so slow that the human mind can not sense the changes that are occurring. While Edgerton improved
scientific research with his methods of capturing high speed phenomena, John Ott (1958) was
pioneering the development of time-lapse photographic techniques. Ott developed techniques
that allowed viewers to see long-term process changes in a “compressed time frame.” The
resulting time-lapse movies allowed the viewer to experience changes at a rate which allowed the
mind to perceive the motion. Time-lapse photography is a means of producing “visual time
compression,” and like “time expansion,” is utilized to analyze phenomenological changes in a
time frame more suitable to the human eye. Time-lapse movies are used to understand
phenomena which occur over an extended period of time in a “compressed time frame” thus
allowing the viewer to better understand the dynamic nature of the phenomena (Attenborough,

Plants grow at a rate that makes them appear static to the human eye, even though we
know they are growing. The use of time-lapse photography allows us to experience the dynamic
nature of plants by visually compressing their growth rates. “Plants live on a different time scale
… and these days we have ways of speeding them up visually so that you can see just how
dramatic their lives are” (Attenborough, 1995, Chap.1). Time-lapse photography not only
provides us with an indispensable tool for studying the dynamic characteristics of seemingly
static phenomena, it also gives us a means of producing a short visual representation of a long
term event.

Today’s time-lapse photography and the making of time-lapse movies is still based on the
same principles as those used in the 19th century. Images are made in a predetermined timed
sequence and shown in a manner that allows the viewer to experience the dynamic nature of the
phenomena. The time interval between successive phases of movement is determined by the
growth or movement rate of the phenomena being observed. In using time-lapse photography to
show or visually analyze various phases of plant growth, the time interval used between images may vary so the viewer has a smooth visualization of the phenomena (Ott, 1958).

**Images and Learning**

It is easy to understand the role images play in recording an event for further study, comparison of phenomena for similarities and distinctions, and the replaying of extremely high and low speed phenomena at speeds more suitable to human observation. What is not as easy to understand is the relationship between learning and the use of images to facilitate learning. What do we know about learning and how does the use of images fit into it? Does the use of prepared images have the same impact on learning as images taken by the learner? We have looked at the tool, now we must look at the application and its value in the learning process.

**Major Learning Paradigms**

Paradigms in this paper refer to basic schools of thought and assumptions associated with a scientific theory. A learning paradigm is a school of thought that is directly related to how human beings think and learn. David Leonard categorizes learning theory into four major schools: humanism, behaviorism, cognitivism, and constructivism (Leonard, 2002).

Humanism advocates knowledge and learning as produced by the maturation of the individual. Humanism theory is based on the assumption that knowledge comes from personal experience and that thinking is a growth process that allows us to develop tolerance and self-acceptance (Pinar, Reynolds, Slattery, & Taubman, 2002).

Behaviorism, which was a predominate paradigm in the 1960’s and 70’s (Novak, 1998b), is based on stimulus and response, with learning taking place when the learner is systematically stimulated by activities provided by the instructor (Leonard, 2002; Pinar et al., 1996). Despite its detractors and opposing schools of learning (cognitivism, constructivism, and humanism),
“behaviorism is still a powerful force in how children and adults [in special education] are taught nearly seventy years after Skinner began his research with animals”. (Leonard, 2003 p.16)

Cognitivism is based on the theory that learning takes place when an individual’s experience leads to the building of a cognitive construct of the experience. It is not simply the addition of a new construct to the individual’s cognitive structure but also a restructuring of the preexisting cognitive structure (Ausubel, Novak, & Hanesian, 1978; Leonard, 2002). Cognitivism advocates learning as a process of inputting information to the mind, processing the data that are entered, and then producing an output. In this paradigm, learning takes place when the student produces the same mental construct as the instructor (Leonard, 2002; Pinar et al., 1996).

The fourth major paradigm is constructivism. Constructivism is learner-centered with the learning generated not from an external source but from within the learner. The learner uses prior knowledge to construct his or her own conceptual understanding. The role of the instructor and learner differ from the other paradigms in that the instructor becomes a facilitator of learning and the learner becomes the generator of understanding. This is opposed to the instructor being the dispenser of knowledge and the learner the absorber as we see in the other paradigms (Collette, Chiappetta, 1989; Leonard, 2002; Mintzes et al., 1998; Tobin, 1993).

Trivial, radical, social, and human constructivisms are subgroups within the structure of constructivist theory (Novak, 1998a; Tobin, 1993). One of the main differences in their theoretical beliefs is the role of social interaction in the construction of knowledge. The human constructivist recognizes that individuals have had diverse experiences and that their conceptual understanding may not be the same as those in the academic knowledge structure (Mintzes & Wandersee, 1998).
Scientific Literacy

The current movement in science reform, which began in the 1980’s, has become known as the era of science literacy (Shamos, 1995). Scientifically literate students were described in the National Science Education Standards (National Research Council [NRC], 1996) as those students who are able to:

- experience the richness and excitement of knowing about and understanding the natural world;
- use appropriate scientific processes and principles in making personal decisions;
- engage intelligently in public discourse and debate about matters of scientific and technological concern; and
- increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers.

Yore, Bisanz, and Hand (2003) stated that science education reform in Australia, Canada, the United Kingdom, and the United States has defined scientific literacy as:

abilities and habits-of-mind required to construct understanding of science, to apply these big ideas to realistic problems and issues involving science, technology, society, and the environment, and to inform and persuade other people to take action based on these science ideas. (p. 2)

Science literacy includes mathematical, physical, geological, and biological literacy as elements of science literacy. The importance of these elements of science literacy is evidenced in the National Science Education Standards (NRC, 1996) and the science benchmarks (American Association for the Advancement of Science [AAAS], 1993). Although we can not truly understand the nature of any subset of these elements in isolation, we can use our knowledge of one subset to advance our understanding of another. The geological and biological evolutions that have occurred since the beginning of the earth can be investigated separately and each adds
understanding to the other when examined in unison (Public Broadcasting System [PBS], 2001, Luhr, 2003).

Encompassed within the elements of biological literacy is the essential understanding of botanical concepts and the importance of plants in sustaining life on earth as we know it. The Botanical Society of America separates the importance of botanical literacy into three major areas: the diversity of life, the development of organism, and the structure and function of ecosystems (Botanical Society of America [BSA], 1995).

**Botany and Science Education**

The National Science Education Standards (NRC, 1996) emphasize the building of scientific knowledge through direct experiences with living organisms. These direct experiences can be achieved through plant-centered, inquiry-based learning. Reproduction, population diversification, adaptation and evolution, can all be investigated by K-12 students in a manner acceptable to both the scientific and non-scientific communities utilizing hands-on botanical investigations. The study of plants and their life cycles facilitates the understanding of diversity of life, shows the interdependency of living organisms, and illustrates the evolution of living organisms which are all essential elements of the science benchmarks (AAAS, 1993).

The Botanical Society of America (1995) emphasizes the need for individuals to understand the role of plants in scientific advancement and their general importance to society. Although plants account for 90% of the biomass on earth (Reinsvold, 1999), they are often ignored, which directly affects scientific literacy. Wandersee and Schussler referred to this as plant blindness or "the inability to see or notice the plants in one's own environment, leading to the inability to recognize the importance of plants in the biosphere and in human affairs" (Wandersee & Schussler, 1999).
The American Society of Plant Biologists (ASPB), in cooperation with the ASPB Education Foundation, developed twelve principles of plant biology (ASPB, 2001) to help K-12 students to perceive and recognize the basic plant concepts. Understanding the role of plants in maintaining a global environment suitable for humans, the manufacturing of pharmaceuticals, and their energy-capturing process should be an essential component of science education (BSA, 1995). At present there are many misconceptions about plants (BSA, 1995; Reinsvold, 1999), and the importance of plants is often overlooked (BSA, 1995). The National Science Education Standards (NRC, 1996), the Benchmarks for Science Literacy (AAAS, 1993), and Botany for the Next Millennium (BSA, 1995) all emphasize the importance of studying plants to a science literate society.

Rationale for the Study

The use of images to provide a visual record of scientific phenomena is neither new nor unique, “…cave drawings and the computer image are both artifacts of the human effort to record nature and render it intelligible” (Robin, 1992, p. 11). These images might be considered “experimental artifacts” based on the work of cognitive scientist Donald Norman since they involve human choice, judgment, and framing. (as cited in Mintzes et al., 1999, p. 132).

The foundation for a constructivist philosophy of meaningful learning and teaching was best expressed by Ausubel’s proposition from the epigraph of his 1978 book, “Ascertain what the learner already knows and teach him [sic] accordingly” (Ausubel, Novak, & Hanesian, 1978, p. 24). The understanding of a student’s prior knowledge is in itself not sufficient to insure meaningful learning. The methods used to link a learner’s existing knowledge to new experiences in a manner that results in knowledge reconstruction and expanded conceptual understanding must be effective. “While much teaching and learning in science classrooms...
remains focused on memorization of facts and application of algorithms, research conducted over the past half century supports instructional practices that depart widely from these approaches” (Mintzes, Wandersee, & Novak, 1998, p. 328).

Constructivism advocates meaningful learning developed through inquiry-based learning. This occurs when prior knowledge is challenged and new understanding is created by restructuring old beliefs, replacing old beliefs with new ones, or reinforcing existing beliefs.

It has been shown that images have played an important role in science education. Research has been conducted on the use of images in text books (Nixon, 2001; Wandersee, 1999), and the use of images to assess scientific understanding (Hypolite, 2003; Nixon, 2001; Wandersee, 1999). The dual coding theory of Paivio (Sadoski & Paivio, 2001; Wandersee, 1999) explains learning enhancement through visual experiences.

One question that has not been addressed to date is whether there is a difference in the understanding of a learner who is engaged in the actual taking of an image as an integral part of the learning activity compared to one who simply studies an existing image. Wandersee acknowledges that “…the majority of photographs taken involve human choice, judgment, and framing” (1999, p. 132). Building on this notion, the cognitive processes involved leading up to the taking of the image may be as important as, or even more important than, the image itself. The analysis of the photograph or series of photographs then becomes visual verification or contradiction of understandings held prior to the moment or sequence of moments captured.

When analyzing Sir Joseph Banks’ illustration of Banksia integrifolia (Musgrave, T., Garner, C., & Musgrave, W., 1998) or Harold Edgerton’s images of the first microsecond of the explosion of an atomic bomb (Jussim & Kayafas, 2000), we can appreciate how new knowledge can be derived from studying these images. But, what about the knowledge gained from the
knowledge construction process? From a constructivist viewpoint it is a natural avenue for meaningful learning, where prior knowledge is coupled with inquiry-based, hands-on activities to build new knowledge.

Research Questions

1. Will time-lapse and stroboscopic photography enhance student understanding of a plant’s interactive structure?
   a. Will imaging increase student awareness and knowledge of plant dynamics?
   b. Will imaging improve student identification of plant structure?

2. Will time-lapse and stroboscopic photography enhance student understanding of plant reproduction?
   a. Will imaging improve student understanding of the differences between pollination and fertilization?

3. Will the process of taking an image enhance student learning?
   a. Will the framing and taking of an image improve understanding of spatial relationships?
   b. Will the framing and taking of an image improve understanding of plant structure?
   c. Will the framing and taking of an image improve understanding of plant design?

4. Will the understanding of photographic techniques enhance a student’s conceptual understanding of scientific information given in image format?
**Definition of Terms**

Benchmarks for Science Literacy - a follow-up to Science for All Americans which specifies how students should progress toward science literacy developed by the American Association for the Advancement of Science. (AAAS, 1993)

Human Constructivism - creating one’s own conceptual understanding through engagement in intellectually demanding activities which facilitate restructuring or reinforcement of prior knowledge.

Imaging - the production of stroboscopic or time-lapse images.

Inquiry-based learning - the construction of knowledge from active intellectual participation in activities designed to promote scientifically sound thought and investigation.

Knowledge construction - using prior knowledge as a building block and to acquire new understanding through personal experience and independent thought.

Science standards - levels of scientific understanding that students need to achieve when progressing through grades K-12; what educational systems must provide to produce scientifically literate students; and the role of teachers in science education. (NRC, 1996)

Science literacy - the understanding of mathematics, technology, natural science, and social science, and the interrelatedness of all the sciences. It is when an individual has the knowledge to understand both natural and man-made events and make sound decisions based on the well-being of the global environment and society.

Stroboscopic photograph - the taking of an image in such a manner as to record that image during an extremely small time frame.

Time-lapse movie - the connecting of a sequence of timed images and showing them in either a compressed or expanded time frame.
Time-lapse photography - the taking of a sequence of images at specific time intervals.

**Gowin Vee**

The Gowin Vee can be used effectively as a research organizer. Named for its V structure, this organizer divides the research into four areas of concern. The left side of the V represents conceptual/theoretical thinking while the right side, the methodological aspects. In the middle of the V is the focus question for the research and any sub-questions. The final section is the bottom-center of the V and shows the research elements that will provide the connection between the other elements of the V. (Mintzes, Wandersee et al., 1998)

![Gowin Vee Diagram](image)

Figure 1: Gowin Vee.
LITERATURE REVIEW

Early Scientific Images

“ALTHOUGH WIDELY SEPARATED IN TIME, the cave drawing and the computer image are both artifacts of the human effort to record nature or render it intelligible” (Robin, 1992, p. 11).

Some of the earliest known images created by man can be seen in the caves of France (Robin, 1992). The Upper Paleolithic limestone caves in the Pyrenees are a treasure trove of paintings and engraved figures that date back over 30,000 years with the caves of Chaunet-Pont-D’Arc and Lascaux containing over 600 such paintings and engravings. The caves at Chaunet-Pont-D’Arc have 21 locations throughout the caves that reveal some of man’s early attempts to record his observations. Cave art such as this has been found in France, Spain, Italy, Portugal, Germany, and the Balkans (Johnson, 2005).

Humans use images to record observations, store visual data for future analysis, provide a means of sharing visual data, and promote recall. These images can be in the form of engravings, three-dimensional models, sketches, or paintings. The media used for image preservation can be as diverse as a cave wall or a computer hard drive. Visual data can also be stored in the form of graphs or tables with the capability of changing from one equivalent form to another without the corruption of data. Visual data is a virtual “snapshot” of the data that provides the observer with another means of understanding the information.

The images left by early humans in the caves were created to fill a need of the creators. The reason for the preservation of observations may be visual documentation of observed phenomena for future reflection by self or others, a means of documenting spatial relationships,
or visually freezing a single moment of time. The needs filled by scientific images can be separated into six distinct categories, each serving a unique purpose: a) observation – images that are simply making a record of what was seen, b) induction – images used to convey the thinking of the observer about what he or she perceived was happening, c) methodology – images that convey how something was accomplished, d) self-illustrating phenomena – images that are produced by nature and show effects generated by natural phenomena, e) classification – images that show how things are alike or different, and f) conceptualization – images that help us illustrate what can otherwise be seen only in our minds (Robin, 1992).

Starr Ockenga’s *Heart of Kenya, Blossom Peacock, and Rilona* (Ockenga, 2002) are images framed by an individual to capture what the observer saw in a single moment of time. Johannes Hevelius’ *Map of the Moon* (Robin, 1992) and Oliver Grunewald’s image of the fiery interior of an active volcano (Luhr, 2003) provide a visual sharing of the experience and capture visual data that could be used for post-experience analysis. Scientists have long used field notes and accompanying sketches to record their observations. Galileo Galilei sketched six phases of the moon (Robin, 1992), Sir John Banks sketched the flora he discovered while on his journey with Captain Cook (Musgrave et al., 1998), and Harold Edgerton captured the dynamics of a bullet entering and exiting an apple (Jussim & Kayafas, 2000). All of these scientists were creating images whose purpose was to record scientific observations and provide future observers the opportunity to see what would have otherwise been lost in time.

Just as a botanist uses a sketch to create a visual record a new flower, a geologist uses a photograph to make a visual record of the layers found in a newly excavated pit, or a chemist uses a series of images to record physical changes during a reaction, a mathematician uses graphs to visually preserve mathematical data. The line graph showing the number of juvenile arrests for
murder over an eight year (Kime & Clark, 201), the line graph showing the duration of a drug’s
effectiveness (Hughes-Hallett et al., 1999), and the bar graph showing the number of pockets in
the clothes of second grade students (National Council of Teachers of Mathematics [NCTM],
2000) are examples of visual storage of mathematical observations.

Images have often been used to explain a person’s thoughts on observed phenomena.

Descartes, in his *Study of the Formation of a Rainbow* (Robin, 1992), uses a sketch to
communicate his thoughts on the origin of rainbows. Henry Moseley’s *The Geometry of the
Nautilus Shell* (Robin, 1992) is his explanation of the mathematical pattern found in the design of
a nautilus shell. Hermann Ryff sketched *Representation of the Trajectory of a Projectile*
(Massironi, 2002) to illustrate his trajectory theory of a cannon projectile. Nicolaus Steno
produced the first geologic cross-section ever made to illustrate his theory on the formation of
the Tuscany geological structures (Cutler, 2003). These examples illustrate how images have
been used by an observer to explain his or her perceptions on the event being observed.

Images are also used as visual instructions to show methods by which a task can be
accomplished. Instructions for assembling a child’s toy, a map to a hidden treasure, and a
diagram for setting up the apparatus for a sophisticated experiment are all examples of this
category. Again, they are an attempt to simplify the information and place it within a context for
better understanding by the observer. William Gilbert used illustrations in *De Magnete* to show
the magnetization of an iron bar (Robin, 1992). The *Guide for Visitors to Ise Shrine* (Tufte,
1990) shows not only shrine locations but also available routes to the shrines. Patricia Wynne’s
*The Reproductive Behavior of the Stickleback* (Tufte, 1997) is an example of how scientists can
illustrate methods used in nature to accomplish a given task. In this case, the image illustrates the
tactics used by the male stickleback to protect the nest from raiding females. The NCTM
Principles and Standards for School Mathematics (NCTM, 2000) uses images to show the steps required in the geometric proof of the algebraic expression representing the Pythagorean theorem.

Images that are produced by nature and show the effects generated by natural phenomena are called self-illustrating images and have broad applications. For example, William Bickel’s A Lightening Stroke and Its Spectrum (Robin, 1992) is a self-illustration of the color spectrum produced by a lightening strike. Harold Edgerton’s Owl (Jussim & Kayafas, 2000) shows the wing motion of an owl landing, while Bruno Barbey’s Pit Crater (Luhr, 2003) illustrates the effect of an impact from a celestial body on the earth. In each of these images, the visual explanation of the phenomena is captured. Electronic graphs, such as an EKG of a human heart beat, an EEG of a human brain, the seismographic image produced by an earthquake, and the oscilloscope image of thunder, also fit into this category. This type of image not only shows the phenomena but provides visual input which simulates scientific thought (Robin, 1992).

Classification images are used to show similarities and dissimilarities. One of the most common images used for this purpose is the periodic table. The periodic table arranges the elements according to similarities and differences of specific characteristics. Carolus Linnaeus used charts in his 1737 work Genera Plantarum to classify plants by their sexual characteristics (Robin, 1992).

Mathematicians use a variety of graphs to visualize mathematical similarities and differences (Gordon, Yunker, Vannatta, & Crosswhite, 1997; Sobanski, 2002). Graphs of families of functions allow the mathematician to visualize and analyze the similarities of functions from a geometric perspective (Godbold, 1998; Hughes-Hallett et al., 1999). The use of simultaneous graphing of multiple event trials provides researchers, designers, and engineers a
means of visual comparison and classification. Frank Golley (1998) used graphs to visualize trends in population of flour beetles living together in wheat.

The sixth use of science images is for the enhancement of conceptual understanding. Sharing what a human mind visualizes can not always be accomplished by language alone. Visual representation of an idea is a means by which the thoughts of one individual may be shared with others. Rutherford’s image of the atom (Massironi, 2002) and Bohr’s model of an atom (Hogness & Johnson, 1954) each represent the conceptual understanding of great scientists explaining the unseen mechanics of the same phenomenon. Without the use of images, the average person would not comprehend what these men of science visualized in their minds. Other examples of images that are used to convey conceptual understanding are Paul Ehrlick’s *A Theory of Immunity* (Robin, 1992), and Watson and Crick’s *Model of the DNA Helix* (Robin, 1992). The great mathematician Benoit Mandelbrot developed a means of visualizing the patterns of irregularities that are found in natural forms (Robin, 1992). Through the use of computer-generated images, people are now able to visualize a very complex concept which is also referred to as “the geometry of chaos”.

**Multiple Images**

It is often impossible for a single scientific image to capture and transmit the dynamics of either a natural or man-made phenomena. As a natural or man-made phenomenon occurs, the changes over time can be so dramatic or so subtle that a single time frame can not capture the essence of the event and may even distort the understanding of what transpired. One means scientists use to visually record events that produce changes over time, is what Edward Tufte called small multiples (Tufte, 1983, 1990, 1997). The use of small multiples to record phenomenological changes over time is not new. Galileo Galilei illustrated six unique
observations in *Six Phases of the Moon* (Robin, 1992). No single image could have captured the changes nor could it have stimulated inquiry as to the cause of the changes. Harold Edgerton used small multiples to show what occurred when a single drop of a liquid fell onto a liquid surface: *Cranberry Juice Dropping into Milk* and *Water Dropping into Water* (Jussim & Kayafas, 2000).

Small multiples have a dual advantage. First they allow the viewer to see the phenomena as it appeared at specific times and second it promotes a mental reconstruction of the relationship between the event sequencing and the physical effects of the event. The information conveyed in Eduard Strasburger’s *Division of the Cell Nucleus* (Robin, 1992) or Claude Nurdisany and Marie Perennou’s *Teasel* (1998) could not be transferred using only a single image.

Small multiples are not restricted to imaging used to illustrate change over time. Joge J. Yunis and Om Prakash’s *The Origin of Man: A Chromosomal Picture Legacy* (Tufte, 1983) is a comparison of a complex data set. John Jackson’s *The Practical Fly-Fisher; More Particularly for Grayling or Umber* (Tufte, 1990) uses small multiples to compare artificial flies. Both of these small multiples are completely independent of time.

**Hand Sketches**

Hand sketches and artists’ renditions of natural and man-made phenomena have been used for centuries to record observations by humans. Cave drawings from France dating back 30,000 (Pinker, 2001; Massironi, 2002; Robin, 1992) gave us visual data on animal species that lived during that period. Sir Joseph Bank’s *Florilegium* (Musgrave et al., 1998) painted in the late 18th century provided a visual record of flora discovered on his journey aboard the *Endeavor*. Sir George Back’s sketch of men fording the Hoarfrost River (Musgrave et al., 1998) made in the 19th century showed the difficulties encountered
by Douglas when exploring the rugged Northwest. The illustration of *Young Wood Stem* (Lindsay, 1992) made in the late 20th century illustrates the cross-section of a woody stem. Every century possesses examples of hand-drawn visual documentation.

**Technological Changes and Images**

Although there has been a continuum of hand-made sketches showing man’s observations over the last 30,000 years, technological advances during the same time period have produced new techniques and equipment that have had significant impact on visual documentation. The accuracy and integrity of scientific images have been in question for a long time and many scientists viewed any image that depends all or in part on the human hand with skepticism (Robin, 1992).

The development of the photograph marked a turning point in scientific imaging. Modern methods of imaging are increasingly being used to supplement sketching or in some cases replacing it entirely with film or digital camera (Wright & Dahl, 1995). The modern photograph began in 1839 when Louis Daguerre disclosed his photographic process (Davenport, 1991; Marien, 2002) and William Fox Talbot published his treatise *Some Account of the Art of Photogenic Drawing-The Purpose of Which Natural Objects May Be Made To Delineate Themselves without the Aid of the Artist’s Pencil (Davenport, 1991)*. Unlike images drawn by the human hand, “photography was adopted as an instrument of science almost from its conception” (Peat, 1998, p.144) and scientists immediately attempted to use this new technique as a means of recording events (Marien, 2002). The photograph provided scientists the means of creating a visual record of phenomena without the need for visual interpretation by the illustrator.

Examining images of the same phenomena taken at various periods of history shows global similarities yet distinctively different detail created by technological advances in
techniques and equipment. An example of this is the images of the moon’s phases drawn by Galilei in the 17th century (Robin, 1992) and those taken by NASA’s Jet Propulsion Laboratory and the California Institute of Technology (Luhr, 2003) in the late 20th century. Although Galilei’s sketches are magnificent, they lack the detail and exactness found in those made using modern technology. As the combination of photographic and electronic flash technology improved, the ability to capture images of high speed phenomena also improved.

Stroboscopic Photography

The recording of high speed phenomenological changes required the combination of high speed cameras and high intensity flashes of light occurring over an extremely small interval of time. High speed stroboscopic photography was pioneered by Harold Edgerton at the Massachusetts Institute of Technology (Jussim & Kayafas, 2000). His groundbreaking high speed cameras, high intensity stroboscopic light sources, and high speed triggering devices allowed scientists to capture images of both man-made and naturally occurring changes never before seen. With high intensity electronic flashes ranging from 1/3,000 to 3/10,000,000 (Jussim & Kayafas, 2000) of a second in duration, he was able to take pictures of a bullet entering and exiting an apple (Jussim & Kayafas, 2000) or the splash crown formed when a drop of milk falls into a dish of milk (Robin, 1992). Edgerton’s high speed photography even allowed scientists to see the initial microseconds of an atomic bomb detonation (Jussim & Kayafas, 2000). High speed photography gave scientists visual data that could be used to reinforce existing theory, question existing theory, and promote new theory. The use of a stroboscope permitted the photographer to capture motion in a manner unavailable to either the single still or motion picture. Using a multiflash procedure (Jussim & Kayafas, 2000) Edgerton was able to produce multiple exposures of an object in motion on a single negative. These new photographic
techniques allowed scientists to capture events as they occurred in either a single-instance image or a multiple exposure format. The need still existed to refine the process of capturing and reproducing what appears to the viewer as continuous motion.

**Early Attempts at Motion**

The beginning of motion pictures was the projection of a single image whose sole purpose was to frighten people. Giovanni da Fontana’s images of demonic shapes in 1420 were refined by Athansius Kircher in the 1600’s with the creation of the first magic lantern (Naughton, 2001). The projected image from the magic lantern gave the appearance of movement and started the era of the motion picture. The illusion of motion was created when two sequential images were quickly pulled back and forth through the lantern (Naughton, 2001).

During the 19th century devices such as the phenakistiscope were used to produce animation from hand-drawn images. Lieutenant L. Wachter of the French Army made a series of drawings depicting his observations of a galloping horse (Deutelbaum, 1979). Wachter’s images were placed in sequence around a phenakistiscope. With the phenakistiscope quickly rotating, the viewer looked through a slot into a mirror and saw the visual illusion of a galloping horse. Similar devices such as the thaumatrope, zoetrope, and praxinoscope all used persistence of vision and the momentary flashing of sequential images in front of the observer and to produce the desired animation.

Attempts at projecting the illusion of motion from still images appeared as early as 1870 when Henry Heyl intermittently projected a sequence of posed still images of him dancing a waltz with a partner on a screen. The projected images along with persistence of vision successfully produced the illusion of watching the couple dance (Deutelbaum, 1979).
In 1873 Eadweard Muybridge was engaged to photograph a horse in full gallop. Muybridge accomplished the task by using a series of cameras with electromagnetic triggers which tripped as a horse ran past a white wall. Although his first attempt was successful, it took five years before the quality of the results were completely convincing. Marshall Deutelbaum cites an article from the October 19, 1878 *Scientific American*, “Before these pictures were taken, no artist would have dared to draw a horse as a horse really is when in motion, even if it had been possible for the unaided eye to detect his real attitude” (1979, p.3). The power of the photograph is illustrated by the fact that Lieutenant Wachter had 16 years earlier described and sketched the exact same images of a galloping horse in his book, *Apercus equestres* (Deutelbaum, 1979). Although Wachter pictures were accurate drawings of a galloping horse, Muybridge’s was created with the first accurate images of a galloping horse showing the power of a photograph.

**First Motion Picture**

Muybridge is credited with producing and showing the first motion picture. On May 4, 1880 Eadweard Muybridge used a zoetrope to show his photographs of animals in motion (Deutelbaum, 1979). Although the illusion of motion had been produced by Heyl in 1870, Muybridge’s presentation was different since it reproduced action whereas, Heyl used posed still images to create the illusion of motion.

The use of a series of single cameras was replaced with the motion picture camera, invented by Thomas Edison (Library of Congress, Motion Picture, Broadcasting, and Recorded Sound Division, 1999). The new device provided a more practical, cost-effective means of producing motion pictures. Early motion picture cameras took images at a rate of 16 frames per second. When the movie was projected a fluid motion was produced but the lag-time between
frames created what was called the “flicker effect.” Increasing the frames per second to 24 and taking advantage of persistence of vision, or afterimaging, solved the flicker problem. Afterimaging in the movie theater is enhanced by the intense light of the projected image and the dark background of the movie theater (Deutelbaum, 1979).

The motion picture has become a common means by which visual data are recorded and analyzed by scientists. But even the motion picture had to be modified to meet the needs of scientific inquiry and understanding. The standard motion picture was used to capture events that occurred at rates which could be easily interpreted by the viewer. Many scientific investigations involved phenomena that changed at extremely slow or fast rates with the results undetectable to humans.

High Speed Photography and Motion Pictures

Some phenomena occur at a rate too fast for the human eye and mind to capture and process (Jussim & Kayafas, 2000). Creating a visual record of rapidly changing phenomena and projecting in a manner that shows continuity and detail required the development of special techniques and equipment. Etienne Marey developed one of the first slow motion cameras with the capacity to take 700 images per second in the 19th century (Leggat, 1995). Harold Edgerton and his partners Kenneth Germeshausen and Herbert Grier pioneered the coupling of high speed photography and motion pictures. Their Oscar winning film, *Quicker than a Wink*, was made in collaboration with Pete Smith of MGM studies and used time-lapse photography to show what really occurs during everyday events (Jussim & Kayafas, 2000). Slow motion movies use “time-expansion” techniques which allow the viewer to see phenomena unfolding in a time frame much longer than that of the actual event. The rate of change of the phenomenon’s physical aspects is visually slowed to a speed that can be processed and interpreted by human vision. Time-lapse
movies differ from regular high speed images in that they project the continuous nature of the event.

**Time-Lapse Photography**

In both the natural and man-made world, phenomena often occur in a time frame so slow that humans do not detect the dynamic nature of the event. Single images can be used to collect visual data at various stages of the phenomena and normal motion pictures can be used to show the phenomena as it appears in real time. But neither of these techniques transmits the change that is occurring within this unique time frame.

At the same time Harold Edgerton was pioneering high speed imaging, John Ott (1958) was pioneering the development of time-lapse photography. Time-lapse is a means of “time-compression.” Time-lapse movies are produced when images are taken at extended time intervals and then projected at a rate that allows the viewer to visually experience the dynamic nature of the event.

Ott’s research with plants included the use of time-lapse photography to record visual data. The workings of the Venus fly trap, the fertilization of a clover fern, and the growth of pollen tubes are areas of botanical research aided by Ott’s use of time-lapse movies (1958). David Attenborough (1995) utilized time-lapse photography to transform what he called the unique time scale that plants live by into a time frame that allowed humans to experience their dynamic nature by the filming of *The Private Life of Plants*.

Although the methods used have changed over time, the need to record visual data has remained the same for over 30,000 years. The hand-drawn sketch is still used today to record observations just as it was in the caves of France (Robin, 1992). The need to see and record detail has led to the development of sophisticated equipment (Jussim & Kayafas, 2000). The
desire to understand what occurs in a time frame other than our own has led to equipment and methods that allow us to visually experience what is happening in other time frames (Ott, 1958). We have created the means of visually freezing time so that the hyperfast phenomenon can be observed and studied (Jussim & Kayafas, 2000). Visual data collection is not only helping the research scientists verify what they know, it is also generating new questions to be answered.

Visual Cognition

The task of understanding how objects and scenes are represented in the brain for the purpose of recognition is one of the hardest and most important questions in cognitive neuroscience. Our visual system is so swift and efficient at identifying our surroundings that we often do not appreciate the true complexity of the task. (I. Bulthoff & H. Bulthoff, 2003, p. 146)

Although our understanding of how the human mind works has improved over time, researchers are still embattled in opposing theories of cognition. Visual scientists such as Helmholtz and Kanizsa differ in their assessment of the relationship between seeing and thinking. While Helmholtz believes they are “intimately related,” Kanizsa believes that they function under separate rules (Carsetti, 2004). One explanation for this dualism is given by Carsetti (2004):

Recent neural models of visual perception have clarified how seeing and thinking operate at different levels of the brain and use distinct specialized circuits. But these processes also interact intimately via feedback and use similar laminar cortical designs that are specialized for their distinct functions. In addition, this feedback has been predicted to be an essential component in giving rise to conscious visual percepts, and recent data have provided support for this prediction. Thus, although seeing and thinking are carried out by different parts of the brain, they also often interact intimately via feed forward and feedback interactions to give rise to conscious visual percepts.” (p. 29)

What we experience through sight is directly related to our visual perception, our memory, and the biological nature of the visual system (Styles, 2005). The highly diverse functions of brain cells, each performing specific visual functions, are then connected through high speed parallel circuits which bring meaning to visual data.
The gathering, recording, and storage of visual data are important to scientific inquiry. Equally important are the means by which the human brain enters, processes, and stores this data. The mechanics of sight and the transduction of what is seen to the neurotransmission within the brain are governed by physical laws that hold true for all humans. The interpretation of the information that is received at the visual cortex is not governed by such absolute laws and is based on the prior experience and conceptual understanding of the observer (Solso, 1994). Some cognitive psychologists posit that visual information is passed on from the eye to the visual cortex through a series of stages. This paradigm is referred to as the information processing paradigm, INFOPRO (Solso, 1994). Since each stage conveys the information to the next stage it is sometimes known as the “conveyor belt” theory.

Once visual information reaches the visual cortex, interaction occurs between various regions of the brain. One example of this is the interaction of visual information with the motor cortex causing the eyes to focus on specific sections of the image. This eye motion can be either diverse with the eye hunting for non-content-specific stimulation, or specific, when the eye searches for a particular location of the image for informational properties (Solso, 1994; Styles, 2005).

Researchers have monitored the interaction between the brain and visual stimulation using eye motion detection techniques. Cognitive scientists then utilize this information to investigate brain-visual stimulus interaction since eye motion is controlled by the individual and is an indicator of volition, attention, and intention. Research has shown that eye motion patterns are dependent on prior knowledge of the observer and that a viewer fixates at specific points on any given image (Solso, 1994; Spoehr & Lehmkuhle, 1982).
The visual processing system within the brain is very complex and selective, with various regions responsible for specific visual functions (Pinker, 1997; Solso, 1994; Styles, 2005). Since the division of visual attributes is so diverse, the brain must also have a means of combining these data into something meaningful. The feature integration theory, FIT (Styles, 2005) posits that meaningful interpretation comes from combining visual and other sensory data with memory data.

Memory utilized during learning depends upon the kind of processing taking place (Styles, 2005). Memory is subdivided into four categories: short term which stores our working memory and where visual-spatial relationships are resolved; long term consisting of semantic memory and episodic memory which records personal experiences; declarative memory which allows us to convey to others what we know; and procedural memory which tells us how the process needed to complete a task (Styles, 2005).

How we store information in the brain for later recall depends on the nature of the information being stored or coded. When abstract concepts are coded into the brain they are done so as language since we have no other avenue or source of information for the brain to process and associate with the concept. If on the other hand the information being stored is concrete in nature, it has an imagery component and can be coded both linguistically and visually. This theory of coding was proposed by Allen Paivio in 1971 (Paivio, 1971; Spoehr & Lehmkuhle, 1982; Wandersee, 1999) and is known as the dual coding theory. This theory not only has implications for the teaching, understanding, and recall of scientific knowledge but also assessment of understanding (Wandersee, 1999).

Researchers theorize that the rate and complexity of response by the brain to visual stimuli is too fast to be accomplished by serial neuron transmission. Although anatomical studies
have shown that visual information is transmitted to the cerebral cortex through one of two routes (Spoehr & Lehmkuhle, 1982), cognitive scientists believe that the high rate of visual reaction to stimuli is the result of simultaneous or parallel transmissions from the cerebral cortex to many regions of the brain by what is called parallel distributed processing (PDP) (Solso, 1994; Spoehr & Lehmkuhle, 1982). Like dual coding, parallel distributed processing plays an important role in both learning and recall.

Parallel transmission of information plays an important role in the interpretation of the visual environment. Visual perception is an action or reaction brought about by the visual environment. Styles (2005) explained the existence of two visual information streams within the visual cortex that analyze visual information. The ventral stream is responsible for analyzing what an object is, and the dorsal stream whose responsibility is analyzing where an object is. At the same time, simultaneous transmissions are made to other portions of the brain where additional visual attributes are analyzed.

A common theme when analyzing the research on visual cognition and perception (Carsetti, 2004; Pinker, 1997; Solso, 1994; Spoehr & Lehmkuhle, 1982; Styles, 2005) is that prior knowledge or experience plays an important role in the interpretation of the visual stimuli. Richard Gregory stated that visual perception was “a dynamic searching for the best interpretation of the available data” (quoted in Styles 2005, p.52). Styles stated that this interpretation was based on memory from past experiences.

Learning Paradigms

It is not surprising that so little is known about the mental processes responsible for children's remarkable intellectual achievements. Even elementary questions remain the subject of controversy and inconclusive findings. For example, there is little agreement about whether children use a general-purpose system to induce the varied principles bearing on language, social structure, etc., or whether different domains engage special-purpose mechanisms in the mind. The disparity just noted for intellectual
development has also been observed in the acquisition of scientific knowledge by adults. Like the child, scientists typically have limited access to data about the environment, yet are sometimes able to convert this data into theories of astonishing generality and veracity. (Jain, Osherson, Royer, & Sharma, 1999, p. 4)

Ashman and Conway defined learning as “the acquisition of knowledge through interactions with, and observations of, the physical world and the creatures that inhabit it.” And problem solving as “the application of knowledge to achieve a desired outcome” (Ashman & Conway, 2002, p. 1). How man thinks and learns has been an ongoing source of debate amongst philosophers, educators, and scientists for many years. David Leonard categorized learning theory into four major schools: humanism, behaviorism, cognitivism, and constructivism. (Leonard, 2002) While there is some overlapping of these theories, each has its own distinct foundational beliefs.

Humanism

Frederick Edwords, Executive Director of the American Humanist Association stated that “Humanism is a philosophy focused upon human means for comprehending reality.” (1989, p. 1). Humanism posits that it is up to the individual to find truth and understanding and that knowledge is a product of personal experience. (Leonard, 2002; Pinar et al., 1996) The humanist philosophy posits that knowledge is based on evidence such as that discovered through scientifically sound inquiry while rejecting knowledge based on faith or revelation. Humanism also posits that knowledge accumulation is linked to the maturing of the individual and an emphasis is placed on the importance of feelings and emotions in addition to knowledge and intellect. “Humanistic education was advocated by a number of science educators who believed that science education should do a better job of portraying science as a human activity and should be more concerned about the emotional response of learners.” (DeBoer, 1991, p. 179)
Behaviorism

The behaviorist paradigm approaches learning from the viewpoint of observable outcome as effects of stimuli. The mental processes involved in the acquisition of knowledge are given little regard in behaviorism. Behaviorism, which started in Russia in the early 1900s with most of the research being conducted on animals, became a major influence of American education by the 1960s (Ashman & Conway, 2002).

There are three types of behaviorism: methodological - centered on the behavior, psychological--centered on the stimuli that creates the behavior, and analytical--centered on the mental state creating the behavior. B.F Skinner combined all three types to create what was call radical behaviorism (Graham, 2005). Skinner’s work has had a lasting effect of education and was prevalent in the 1960s and 1970s (Mintzes et al., 1998) and is still very influential within our school systems today. Leonard (2002) stated that despite the 70 years since Skinner started his research and opposition to it, behaviorism still has a major effect on teaching and assessment. Part of its longevity is due to school accountability and the fact that behavioral objectives provided a means of assessing curriculum and instructional strategies in an efficient, quantitative manner. (Pinar et al., 1996)

The Stimulus-Response Theory (Ashman & Conway, 2002) is basic to the behaviorism education paradigm. This can be readily seen in the use of the phrase “the student will be able to” where student expectation are enumerated in the form of responses to academic stimuli. Learning becomes a sequence of steps with desired observable outcomes and immediate reinforcement. Behaviorists believe that the success or failure that a student achieves will have a lasting effect on the student’s future behavior. From an educational standpoint, this was
interpreted to mean that if a student was shown an approach that produced success, they would be likely to use this same approach in the future (Ashman & Conway, 2002; Leonard, 2002).

**Cognitivism**

Whereas behaviorism is centered on the outward or behavioral signs of learning, cognitivism is centered on the inward or structural changes within the mind that occur during learning. Cognitivism theory posits that learning can take place even without outward behavioral signs (Buell, 2005) and that in addition to new cognitive construct, restructuring of old cognitive structure occurs (Ausubel, 1968). Cognitivism is concerned with the internal workings of the brain and the process of thought that produces an action.

Cognitive learning theory has its foundation in the study of memory (Ashman & Conway, 2002). The cognitist believes that without memory there is no learning and that prior knowledge and experience play an important role in the learning process. The transmission of that knowledge and it’s integration with sensory input are the basis for learning.

**Constructivism**

Constructivism is based on the theory that knowledge is built or constructed through the experiences of the individual. Knowledge is changed or reinforced through new experiences and truth changes as old knowledge is modified by these experiences (Pinar et al., 1996; Mintzes et al., 1998; Tobin 1993) Although knowledge is constructed by the individual it is done so under the constraints of the society in which the learner presides.

**Human Constructivism**

Within the theoretical structure of constructivism lies the theory of human constructivism. Mintzes et al. (1998) stated:

In contrast to the notions of the radical and social constructivists, Human Constructivists take a moderate position on the nature of science. On the one
hand, we find the views of classical “logical-positivists” intellectually indefensible, on the other; we think that many constructivists have created a relativistic mind-world that is ultimately self-defeating. We prefer instead a view of science that acknowledges an external and knowable world, but depends critically on an intellectually demanding struggle to construct heuristically powerful explanations through extended periods of interaction with objects, events, and other people. In its simplest form, we believe that human beings are meaning-makers; that the goal of education is to construct shared meanings and that this goal may be facilitated through the active intervention of well-prepared teachers. (p. xviii).

Human constructivism builds on the philosophies of Piaget and Ausubel by centering meaningful learning on the human mind’s ability to build new understanding by developing links between old experiences and new knowledge (Mintzes et al., 1998; Palmer, Cooper, & Bresler, 2001; Scholnick, 1999). As with all constructivist theory, learning is constructed by the learner with effective learning taking place only when it is driven by prior knowledge of the learner (Novak & Gowin, 1984; Collette & Chiappetta, 1989).

Human Constructivism espouses that meaningful learning occurs when a restructuring of conceptual understanding takes place within an individual’s mind. This restructuring can be in the form of a “weak” restructuring process wherein only slight changes in conceptual understanding take place through a process called subsumption. There are times when a “strong” or radical change in conceptual understanding and knowledge restructuring occurs. This is done through a process called subordinate learning. In both cases, the meaningful learning occurred because knowledge was created by the human mind and was linked to prior knowledge (Mintzes & Wandersee, 1998; Mintzes, Wandersee, & Novak, 1999).

Human experience and the anchoring of new knowledge to prior knowledge is an important aspect of Human Constructivism. The experience of the individual plays an important role in the meaningful learning that will take place within the life span of the individual. Whether through subsumption or subordination, meaningful learning is directly related to memories that
connect to prior experiences and create the need for rethinking prior understanding and restructuring conceptual understanding. *Science for All Americans* (AAAS, 1989) holds that position that people are the constructors of their own knowledge and learning occurs when connections are made with existing beliefs. Constructivists prefer not to use the term “beliefs,” and prefer the term “conceptual framework.” It follows that knowledge not connected by multiple links to the learner’s conceptual framework on how the world works will easily be forgotten or is useless.
METHODS AND MATERIALS

Sample

The sampling technique used in this study was convenience sampling. This technique was chosen to accommodate the following requirements of the study: students whose required curriculum would be compatible with the research goals, a teacher and school administration who would allow altering the normal curriculum sequencing to accommodate the study, sufficient space so that equipment could be set up in the classroom for the entire duration of the study, permission from the school system for the investigator to conduct the classes two days each week for six to seven weeks, and a site located within a reasonable commuting distance of the investigator. It was also important to have a student population where the majority of the students had a similar science background.

The school selected was a small, rural, Louisiana combination junior and senior high public school with grades six through twelve. The initial sample consisted of two seventh-grade science classes. The control class consisted of 21 students that included two transfer students from a neighboring public school and one from a non-public school within the parish (i.e., Louisiana’s name for a county). The initial treatment group had 25 students that included two transfer students from the same neighboring public school and two transfer students from the same non-public school.

The current Louisiana Grade Level Expectations (see Appendix A) and the Louisiana Comprehensive Curriculum provided very limited opportunities for the study of plants, their life cycle, photosynthesis, and their overall role in the environment. Seventh-grade science students were selected since the study aligned with required state science curriculum for this grade level as mandated by the state. Their regular teacher randomly assigned numbers to each student so
that anonymity would be maintained throughout the study. He also divided each class into smaller groups of four to five students to facilitate the small group work during the study.

The school system and school administration, as well as the classroom teacher, have a good working relationship with the researcher due to previous professional development activities he conducted throughout the parish and at this school. The majority of the students in this school have been taught by the researcher when he modeled lessons for teachers. As a result of prior contact, permission was granted quickly to conduct the study and allow the plants and equipment to remain in the classroom.

Community stability in this rural area accounts for almost 85% of the students involved in the study having the same science teachers and homogeneous science backgrounds throughout their previous educational experiences. The remaining students in the two groups came from similar communities within 15 miles of this school, with similar educational milieu.

Institutional Review Board

In accordance with Institutional Review Board policy, both a signed participant letter of assent and a signed letter of parental/guardian consent was required for each participant. All students and their parents agreed to participate in the study.

An application for exemption from the oversight of the Louisiana State University Institutional Review Board was submitted (see Appendix B) and approved. The request for exemption was based on the criteria stated in Part B of the Application for Exemption from Institutional Oversight: (a) the research is in an education setting and the research will evaluate normal educational practices with approval of the local superintendent, (b) the research did not involve vulnerable people and the participates are not identifiable, (c) letters of assent and consent (see Appendix C) were obtained from participants and their guardians.
Focus of the Study

Although still and motion pictures have long been incorporated in science education, research is lacking as to the effectiveness of these images as a learning tool. In correspondence with Felice Frankel (personal communication, January 5, 2005) noted research scientist/photographer at the Massachusetts Institute of Technology, and Dr. Roger Hangarter of Indiana University (personal communication, January 4, 2005), who is known for his use of time-lapse imaging to study plant behavior, both individuals indicated that they were unaware of any research whose focus was on the effectiveness of time-lapse imaging as a teaching tool. Dr. Hangarter stated that he had conducted an exhaustive search for this information for a grant proposal and could not find any reference to prior research findings. He also stated that all he could do was quote David Attenborough (1995) and that this knowledge would be valuable for future research proposals.

In his own search for previous studies involving the use of images to enhance learning, the researcher began to question whether or not a significant difference in conceptual understanding would occur if the students captured their own images compared to using pre-existing images during the course of inquiry. Based on principles of human constructivist learning theory, the researcher extended his questioning to include the enhancement of conceptual understanding when a student has personal experience in time-lapse and stroboscopic imaging and is exposed to scientific information created by these photographic techniques. This became the focus for this study as it is my belief that this will be of greater importance for contribution to our knowledge base.
Protocols

All lessons presented to the students (see Appendix E) adhered to the National Science Education Standards (NCR, 1996), the Louisiana Science Content Standards, and the Louisiana Science Grade Level Expectations for Grade 7, and were taught only by the researcher. Student questions that arose during the days the researcher was not present were noted in the students’ field notebooks. The regular classroom teacher took the role of an observer on days that the study was conducted and maintained a notebook of his observations. The investigator also maintained a daily notebook of observations and reflections.

The researcher met with the school administrators prior to approaching the teacher with the request to conduct the study. During this meeting the researcher outlined the purpose, time frame, curriculum compliance, and other information pertinent to the study. The researcher met with the classroom teacher after administrative permission was given for the study. The teacher was given an overview of the study to be conducted, copies of daily lesson plans and handouts, and detailed information on the roles and requirements for all of the participants.

The study was explained to the students in both classes including the non-participation option that each student could exercise, and the safeguards used to insure student anonymity. Assent and consent forms were sent home to be completed by the students and their guardians. All forms were returned, properly signed, before the study began.

Materials

A complete list of the equipment and materials used in this study can be found in Appendix D. The researcher thinks it is important for those who may conduct similar research in the future to understand the difficulties associated with acquiring amaryllis (Amaryllis belladonna) that will bloom in the early fall semester.
Amaryllis Bulbs

In preparation for the study, a search was conducted to locate 30 amaryllis bulbs that would bloom from late September to mid-October. Since this is not the normal blooming period for commercially grown amaryllis, a world wide search was conducted. After a large investment of time which produced no results, the researcher located a member of the Houston Amaryllis Society who referred him to Paul Romijn, a grower in Hillegom, Netherlands. Mr. Romijn had 30 bulbs with girths of 42-44 cm. that would bloom during this time period and would ship them to the researcher on August 1\textsuperscript{st}. Mr. Romijn gave the researcher instructions as to the temperature and humidity the researcher needed to maintain the bulbs until it was time to plant them for blooming. The researcher bought a refrigerator and installed temperature and humidity sensors that would be needed to properly maintain the bulbs.

When the boxes arrived from the Netherlands, the researcher was surprised to find that half of the shipment had been confiscated and destroyed by an inspector for the United States Department of Agriculture in Chicago. The boxes only contained 15 of the bulbs and did not include a phytosanitary certificate which is required when live plants or bulbs are imported into the United States. In a phone conversation with Mr. Romijn, he informed the researcher that there were no more bulbs in the Netherlands that could be forced to bloom during the required time span. He also told the researcher that he would contact other suppliers in Brazil to see when he could get the needed bulbs. Fortunately, suitable bulbs were found in Brazil and marked for shipment to the Netherlands where they would be forwarded to the researcher. As with the first shipment, the proper paperwork did not accompany the bulbs and these bulbs were also destroyed. While discussing the problems with the shipments with an inspector, the researcher found out that during the off-season the normal shipping agents are not available and it is
common for inexperienced people to handle the shipping and leave out the certificate. The agent told the researcher that he had removed three packages that day for the same reason. His advice was to specifically request that the shipper personally insure that a phytosanitary certificate is included when ordering plants and bulbs from outside the United States.

Since the researcher had only received half of the bulbs that he wanted for the study, the researcher dug up amaryllis bulbs from his own flower beds for the students to dissect and use to explore bulb structure and dynamics. These bulbs were suitable for this particular phase of the study even though they were not prepared for force blooming.

During week 3 of the study, the researcher discovered a shipment of amaryllis bulbs that had been shipped early to a new WalMart store in the area. Although their girth was only 24-30 cm, the researcher immediately bought an additional 50 amaryllis bulbs to augment what had previously been shipped.

**Daylilies**

When the growth rate of the amaryllis was slower than previous field testing, daylilies (*Hermerocallis* sp.) were purchased to accommodate the dissection of flowers. Daylilies were used because their flower structure is very similar to that of the amaryllis.

**Tree Seeds**

Seeds that used an aerodynamic means of dispersion were needed for lessons on seed dispersal. Although many seeds use wind dispersion, the researcher needed a seed large enough for the students to actually see the aerodynamics. The researcher decided to use tree seeds that had “wings” and simulated a helicopter like rotation as a means of increasing their dispersion radius. Knowing that the box elder maple had a seed that rotated appropriately, the researcher was fortunate to find Gary Field of the Anglegrove Tree Seed Company in Hабour Grace,
Newfoundland, who could supply the researcher with what he needed. The researcher relied on his expertise to choose six varieties of seeds that would be best suited to the study. The names of these seeds are included in the materials list (see Appendix D).

**Dark Room**

In order to make multiple exposures on a single image, the object to be photographed must be exposed to multiple flashes from an intermittent bright light source while being protected from any other source of light. A portable dark room, 5.5 ft wide by 5.5 ft high by 8.5 ft long, was constructed that could be used within the regular classroom. The room consisted of a frame made from PVC pipe coated with black paint. The frame was covered with black felt cut and sewn together for ease of assembly. A piece of black felt was also used on the floor as a base (see Appendix E).

**Procedure**

The research was conducted over a 7-week period with the researcher working directly with the students two days each week during weeks 1 through 5 and week 7. Due to a scheduled school holiday, it was only possible to work with the students one day during week 6. This extended period was required to allow for the normal growth of the plants being studied by the students in the research. All lessons (see Appendix G) were inquiry-based, aligned with the Louisiana Grade Level Expectations and the National Science Education Standards, and approved by the teacher. The researcher facilitated the use of photographic equipment by the treatment group but was not involved in the actual taking of images. The lessons were taught in either a whole-class setting or with students working in groups of four or five.

**Pre- and Posttesting**

The assessment instruments developed focused on the identification and function of plant
organs. The tests each contained the same 20 multiple-choice items and 8 matching items (see Appendix F), with only the order of the questions changed from the pre- to posttests. The pretest was administered one week prior to the start of any work with the participants and the posttest was given on the final day. All test items were developed by the researcher using the Louisiana Grade Level Expectations (see Appendix A) and the National Science Education Standards as guides.

Attitudinal Survey

Immediately following the completion of their pre- and posttests, each participant was asked to complete a botany attitudinal survey. The attitudinal survey was adapted from a biology attitudinal survey developed by James Russell and Steven Hollander (1975). Russell and Hollander emphasize that measuring attitudes by observation alone is very difficult. The instrument they developed utilized both a Likert-type scale and a semantic differential scale. The Likert scale questions allow the participant to express the degree to which they agree or disagree with a given statement about biology, while the semantic differential scale allows the participant to express their feelings toward biology.

Overview

The researcher gave a general overview of the study and its goals to both the control and treatment groups after they completed their pretest and attitudinal survey. The students were allowed to ask the classroom teacher any questions they had about the research. The teacher had done an excellent job in providing pertinent information to the students prior to taking home their consent forms so there was only one question. They wanted to know if they would be graded for the work they did during the study. The teacher informed them that the material covered in the study was part of the seventh-grade science curriculum and he would count all
activities and the posttest as part of their grade. These criteria assisted in making the study an integral component to their classroom work and one the students took seriously.

**Equipment Training**

On day 2 the researcher met with the treatment group to provide training on the proper use of the available digital imaging equipment. A survey of the students showed that only five had no prior experience with a digital camera. After a brief overview of all the equipment the students were divided into their small groups and given an activity sheet to complete with each piece of equipment (see Appendix E). Each group was given their own camera to use throughout the study and three additional cameras were available for any student to use. The groups were rotated to various workstations so they could take the necessary images during the study with little or no assistance. The student practiced time-lapse imaging techniques using a Casio QV-2900UX camera. Four of the cameras with time-lapse capabilities would be used for this purpose.

The researcher reminded the students that they should think of the pictures as a notebook of what they had studied each day and that at the end of the project they would be asked to make a poster of an amaryllis, its organs, and their functions. The students were also reminded that they had unlimited use of the camera when taking pictures of the plants.

**Plants and Bulbs**

Starting with week 2 of the study, amaryllis bulbs were planted by both the control and treatment groups over the next five weeks. Four additional bulbs were used for time-lapse studies; two of the bulbs were grown in the classroom to be photographed there and two were grown and photographed in the homes of selected treatment group students. When an additional supply of amaryllis bulbs was located in week 3 of the study, each student was given his/her own
amaryllis bulb to plant. The students were given instructions in the growing of amaryllis indoors. Each student was given the responsibility of taking care of his/her own flower as well as a shared responsibility for the class flowers.

In addition to the amaryllis being grown by all of the students, two other full-grown, blooming plants were introduced into the classroom. The first plant, a mandevilla (*Mandevilla* sp.), with flowers that resemble a morning glory, was brought into the classroom in week 3 and 12 daylilies were introduced in week 4.

**Control Group Images**

The majority of the images used by the control group were images that existed prior to the study. The pictures of the amaryllis organs (see Appendix I) were taken by a seventh-grade student during field testing with the same equipment used by the treatment group during the study. Other images included clips from *The Private Life of Plants* (Attenborough, 1995), a large poster of a flower with of the organs labeled, and various sketches of leaf and bulb structures. A ProScope™ video microscope was connected to a laptop and projection device was used to show images of microscopic sections of the amaryllis being grown in the classroom. Other images used by this group and produced during the study were taken in the school science laboratory by the treatment group during the dissection of daylily flowers. The students were given no instructions nor participated in any discussions pertaining to the methods used to produce any images viewed in the study.

**Treatment Group Images**

The treatment group was given the opportunity to take their own pictures whenever possible. The students were given free rein to decide on the number of pictures they wanted to take each time. They were told that at the end of the study some of these images would be used
to create a poster showing the plant organs and their functions. They were also told that images could be used to tell a story, ask a question, or pass on their observations to others. During the taking of the pictures the researcher and classroom teacher acted as monitors and did not have input into the image-taking, except for technical assistance with the equipment. The treatment students were not shown any of the still images used with the control group.

In addition to the regular still images, the treatment group set up two time-lapse cameras in the classroom. Each camera was independent and used to photograph different amaryllis plants. The cameras were set to take images of the growing plants at one hour intervals and students were assigned to check and adjust the framing of the cameras with the plants. Since the researcher knew the possibility of problems associated with long term time-lapse imaging from previous experiences, a backup plan was created. The teacher selected two students from the treatment group who each took the necessary equipment home to independently take time-lapse images in the same manner as those in the classroom.

The treatment group also had the opportunity to take images using the Motic Digiscope™ (designed for young students) and ProScope™. Both instruments are digital microscopes with software that gives them the capability of taking single images, time-lapse images, and movies. The ProScope™ is a hand held digital microscope that provides flexibility, maneuverability, and quick focusing not available with conventional digital microscopes. The ProScope™ included the educational package which gave the students the option of 10, 50, and 200 magnification.

In addition to the student-generated images, the treatment group viewed the series The Private Life of Plants (Attenborough, 1995). Unlike the control group, the treatment group was either instructed in the techniques used to generate the images and/or engaged in a discussion of
the techniques before the viewing. The only image viewed by both groups was the poster of a
cross section of a flower with the organs labeled.

Posters

At the end of the study, both the control and treatment groups were given the direction to
create a poster that conveyed what they had learned. The treatment group received thumbnail-
sized copies of the amaryllis from which to choose, while the control group participants were
given thumbnail-sized copies of the daylily images available to them. The teacher provided time
when the researcher was not present for both the control and treatment groups to meet and design
their poster boards. They were informed that that any picture they selected would be duplicated
on the top half of an 8.5 by 11 inch sheet of paper and they could then use the bottom half to add
information if they so desired. They had to make their own decision as to how many images they
needed since the researcher placed no limits. The researcher picked up the picture requests and
delivered the final copies the following day. Each subgroup had one week to complete the
posters. The teacher was instructed to allow the students to complete the work with no assistance
or advice from him.

Field Notes

During the study, every participant was given a field notebook to be kept throughout the
experience and written suggestions as to what should go into it (see Appendix J). In addition to
the participating students, both the teacher and the researcher maintained a field notebook. These
were collected by the researcher at the end of the study for analyses. As with all materials
completed by the students, anonymity was maintained by the use of a numerical code provided
by the teacher.
Lessons

The lessons for both the control and treatment groups were a balance of lecture, discussion, and hands-on, inquiry-based learning (see Appendix G) which focused on the students’ understanding of the composition, function, and interdependency of the individual organs. Whenever possible both groups were allowed to explore the plant organs being studied on their own. The only difference was that the treatment group was permitted to take pictures of the plant organs and the use and/or taking of images was an integral part of each lesson.

The images taken by the treatment group were available for their viewing on the cameras, computers, with printed copies made available by the researcher. The students shared and discussed their images within their own small groups, with members of the other groups, and with the researcher. Both classes were required to go to the computer lab on one of the scheduled visits to comply with a school technology requirement. The control group was directed to investigate the ThinkQuest Library site at http://www.thinkquest.com/3715/pollin5.html where they explored plants and pollination. The school technology coordinator allowed the treatment group to work on their images while in the computer lab. The images that each treatment group had taken to this point were loaded into the computers and the students worked in their small groups to begin the task of selecting images to use for their poster board display. They also performed some editing tasks by deleting photographs they were not interested in using.

The study of photosynthesis, respiration, and transpiration were incorporated into the lessons. The lessons included the functions of each of the organs in these processes. Only one scheduled activities was deleted due to unforeseen time restraints. This used a cut flower and colored water to show how water moves throughout the plant. The treatment group was asked to document this with the aid of time-lapse imaging.
The study of plant propagation by asexual and sexual reproduction started with the day 3 lesson. The lesson focused on understanding the parts of the bulb and their functions. Since offshoots were associated with the bulb, asexual reproduction was introduced. A discussion of cuttage (severing) as a means of asexual reproduction was included along with a discussion of the three parts of the bulb needed for asexual reproduction. The lesson ended with the dissection of an amaryllis bulb and a discussion on the fully developed bud within the bulb. Sexual reproduction was covered in subsequent lessons. These lessons focused on plant reproductive organs, their function in the reproductive cycle, pollination versus fertilization, and the role of pollinators. Both groups viewed pre-existing time-lapse images in an activity to determine the rate pollinators come in contact with a flower. The symbiotic relationship of plants and pollinators was studied with the aid of clips from *The Private Life of Plants* (Attenborough, 1995) along with the natural pairing of plants and pollinators.

The lessons ended with a study of natural seed dispersal mechanisms. Clips were again shown from *The Private Life of Plants* (Attenborough, 1995) along with images found in the *Metamorphosis of Flowers* (Nuridsany & Perennou, 1997) to both the control and treatment groups. This lesson included a hands-on activity where each student cut out a paper device called a Motor Rotor (NASA, 2006). The device simulates the natural motion used by seeds such as those found on the maple to assist dispersion. The students were then divided into their small groups and given six varieties of tree seeds (see Appendix D). The students dropped and observed the aerodynamic behavior of each variety of seed and compared it to the spinning of the Motor Rotor. The treatment group had one additional activity. In groups of four, these students were led into a black room (see Appendix E) where they were taught how to use a strobe light to take images of an object in motion at various stages. They first photographed a swinging
pendulum and viewed the resulting images and then photographed the Motor rotor which modeled the falling of the seeds they had just investigated.

**Metamorphic Behavior**

The metamorphosis of flowers was discussed by both groups throughout the study with reference made to Arber’s (1946) translation of *The Metamorphosis of Plants* by Johann Wolfgang von Goethe. Passages from this work were shared for discussion. The participants were asked to think about the metamorphic process while examining or creating image’s during the study. They were also asked to record in their field notes any observations or questions they believe were relevant to this process.

**Interview**

Research authority Patton (2002, p. 340) stated “We interview people to find out from them those things we cannot directly observe.” Keeping this in mind, five participants from each group were randomly selected by the teacher to be interviewed privately. The science teacher was also the PE teacher for both classes at the same period in the afternoon. Arrangements were made to use the same classroom setting as the study for interviewing the students during their PE class. The students were interviewed privately, with each interview lasting approximately five minutes. The interview approach was that of a standardized open-ended interview (see Appendix L). Only the participant’s group affiliation and responses were recorded to insure anonymity.

**Experimental Design**

The mixed method design used for this study was concurrent triangulation. This design accommodated the simultaneous collection of both qualitative and quantitative data as well as facilitated the use to both types of data in a corroborative manner during the analysis of the research findings. Qualitative data were collected from student, teacher, and researcher daily in
the form of observation records, and poststudy interview with the participants and teacher. Quantitative data was obtained from pre- and posttesting, and pre and post attitudinal tests.

The selected mixed method approach gave the researcher the freedom to use any available method or combination of methods to achieve the goals of the research. Tashakkori and Teddlie (1998) expressed the opinion that once the question was established, it was the researcher’s responsibility to use any method available to come to a successful completion of the project. The use of mixed methodology promotes the collection and analysis of data that would have otherwise been overlooked during the project. (Patton, 2002) An example of this would be that the exclusive use of quantitative methods would have disallowed the consideration of tacit knowledge when formulating conclusions to our research questions. Lincoln and Guba (1985) emphasized that although naturalistic inquiry stresses the use of qualitative methods, quantitative methods are also important to the naturalistic researcher. Qualitative methods are more appropriate when the study includes research with humans-as-instruments whereas quantitative methods are more appropriate when summative evaluations are desired. Newman and Benz (1998) posit that a quantitative and qualitative dichotomy does not really exist and that a continuum exists from quantitative to qualitative and from qualitative to quantitative.

Patton made the statement that “Triangulation strengthens a study by combining methods.” (2002, p. 247). The selection of the concurrent triangulation method gave this research the advantage of cross-verification through corroboration of data. Denzin identified four basic types of triangulation: “(1) data triangulation, the use of a variety of data sources in a study; (2) investigator triangulation, the use of several different researchers or evaluators; (3) theory triangulation, the use of multiple perspectives to interpret a single set of data; and (4) methodological triangulation, the use of multiple methods to study a single problem or
program.” (quoted in Patton, p. 247) This study incorporated three of the four basic types of triangulation: data, investigator, and methodological triangulation.

Patton (2002) points out that the advantage of quantitative methods is the ability to gather data which is easily compared and statistically aggregated from a set of specific questions. Qualitative methods, on the other hand, have the advantage of providing in-depth inquiry but provide little data from which generalizations can be made. By combining the two methods, the study used both advantages to completely investigate the research question.

The options of using only qualitative or quantitative methodology were given consideration. The use of only quantitative methods was not considered appropriate for this study since quantitative methodology would have omitted data relative to changes involving the human experience in the study. The use of only qualitative methods was not considered appropriate because this data would have omitted data on possible differential content knowledge growth. For these reasons, a mixed methodology design was used in this study.

The concurrent triangulation method was selected from the numerous mixed methods available since this design best fit the needs of the study. Simultaneous data collection was preferred due to the limited time allowed for data collection in the classroom. Parallel studies would have presented problems with finding multiple locations to conduct the study and the logistics of two locations. Consecutive studies would have lengthened the study and created a conflict with overlapping, mandated, standardized testing which would be unacceptable to the school system.

Although triangulation using both qualitative and quantitative data was possible, it did not mean that the results would be easily combined to provide a single view of the results. There are biases associated with each data type and these biases were taken into consideration when
analyzing the findings. The qualitative and quantitative data collected in this study were used for comparative analysis.

The preparation and decision-making for this study was enhanced by the use of the Gowin Vee (Novak & Gowin, 1984). The Vee is a visual aid that helps guide the researcher in connecting conceptual and theoretical views with research methods. The Vee constructed for this study can be found in Appendix N.
RESULTS AND DISCUSSION

Contextual Background

The school used in this research was a new school that still had construction going on when the academic year began. The finishing touches on the school are still in progress. The school combined the sixth through eighth grade from a PreK-8 school with the sixth and ninth through twelfth grade from a school that housed both elementary (PreK-6) and a senior high school (9-12). Both of the former schools were rated as schools in decline by the Louisiana Department of Education due to declines of 8.3 and 13.6 points respectively in their school performance scores and were placed in academic assistance. The vast majority of the student population is categorized by the Louisiana Department of Education as At-Risk with over 88% eligible for free lunch and another 2% for reduced lunch. The high number of at risk students is indicative of low performing schools. The student demographics, as shown in Table 1, indicate that the student population is composed of over 77% majority students.

Table 1

School Demographics

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<th>Category</th>
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<td></td>
<td>Total</td>
<td>Percent</td>
<td>Total</td>
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<tr>
<td>At Risk</td>
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<td>248</td>
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As part of the Louisiana accountability program eighth grade students are required to take the Louisiana Educational Assessment Program (LEAP) 21 test. This test is given in the spring and is a criterion-referenced test (CRT). The test scores for this school indicates a steady increase in the percentage of students leaving the junior high over the last four years with an unsatisfactory achievement level in science, as shown in Table 2.

Table 2

LEAP 21 Science Test Scores

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<td>10</td>
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</tbody>
</table>

Prior to the 2005-2006 academic year, the sixth grade students were required to take the Illinois Test of Basic Skill (ITBS) which included a science component. Unlike the LEAP, the ITBS was a norm-referenced-test (NRT). In the spring of 2006 the ITBS was replaced with the integrated Louisiana Educational Assessment Program (iLEAP). The iLEAP was designed as both a criterion-referenced and norm referenced test. The current seventh-graders participated in the sixth grade iLEAP testing during the spring of 2006 with test results, as shown in Table 3, similar to the eighth grade LEAP.
The staff was composed of teachers from both schools and the administrative staff from the high school. Many of the teachers and administrators are life long residents of the local area. Ten of the current teachers had participated in professional development projects conducted by the researcher.

Sample

The students participating in the study comprised two of the three sections of seventh-graders in the school. Until the fifth grade, the students had been in the traditional self-contained classroom. Starting in the sixth grade the students began departmentalized instruction with daily science classes of 50 minutes. The school has only one seventh-grade science teacher with the control group meeting for science first hour and the treatment group third hour.

Table 3

<table>
<thead>
<tr>
<th>Classification</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced</td>
<td>00.00</td>
</tr>
<tr>
<td>Mastery</td>
<td>09.23</td>
</tr>
<tr>
<td>Basic</td>
<td>47.69</td>
</tr>
<tr>
<td>Approaching Basic</td>
<td>26.15</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>16.92</td>
</tr>
</tbody>
</table>

Both classes experienced the addition of a new student just past the mid-point of the study. The Treatment group had one study who missed the entire study due to a long term illness and another student who moved to another school week 2 of the study. These four students were
not included in any of the statistics used for this study. The change in treatment group size was beneficial to the study since it decreased the difference in group size.

The demographics for both groups were similar (Appendix N). As can be seen in Table 4, the percentage of male and female students in both groups is almost identical. The percentage of majority students is 7% greater in the treatment group but in terms of actual students it would only take 1 more majority student in the treatment group to have approximately the same ratios.

Table 4
Participant Demographics

<table>
<thead>
<tr>
<th>Control Group</th>
<th>Treatment Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>52.4 %</td>
<td>47.6 %</td>
</tr>
<tr>
<td>Black</td>
<td>Hispanic</td>
</tr>
<tr>
<td>14.3 %</td>
<td>4.8 %</td>
</tr>
<tr>
<td>Hispanic</td>
<td>White</td>
</tr>
<tr>
<td>73.9 %</td>
<td></td>
</tr>
</tbody>
</table>

In addition to investigating the group gender and ethnicity composition as possible variables, an independent t-Test was run using the iLEAP scores (Appendix N) from both groups. The purpose was to determine if a significant difference existed in the science knowledge of the groups as represented by the mean score of each group on their most recent standardized science test. The null hypothesis assumed that no significant difference existed and the results, as shown in Table 5, were in agreement. Levene’s Test indicates that the test scores have approximately the same variance. The significance value of .964 for the t-test for equality at \( \alpha = 0.05 \) indicates no significant difference between the groups as measured by the participants’ sixth grade iLEAP scores.
Although every class has its own personality, the researcher observed no marked
difference in the “class personalities.” Throughout the study the researcher found the students
enthusiastic and excited about participating in the study. The students often commented about
their lack of previous experiences with plants. Comments such as “I didn’t know a plant had so
many parts,” “I think it was so cool to what’s inside a plant,” or “I never though of plants as
being alive” were recorded throughout the study.

Table 5

Independent t-Test of 6th Grade iLEAP Science Scores

<table>
<thead>
<tr>
<th>Levene’s Test for Equality of Variance</th>
<th>t-test for equality of means</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Sig</td>
</tr>
<tr>
<td>Equal variance Assumed</td>
<td>1.420</td>
</tr>
<tr>
<td>Equal variances Not assumed</td>
<td>-.046</td>
</tr>
</tbody>
</table>

The students were inquisitive with new discoveries generating questions. One student
made the following entry in his field notes: “Today I learned a lot and it was fun. We learned that
when a plant is grown, it can have a new plant inside the bulb. What if there were two bulbs
together. Would anything change? If so what would change and how?” Both the teacher and the
researcher commented “the students seem to be staying on task and involved in the learning
process.”
Since these students lived in a rural setting, the researcher assumed that they would have a basic knowledge of plants. One of the major industries in the area is forestry, with the trees grown for the paper industry. Knowing the cycle from planting to harvesting to replanting does not always entail an in-depth understanding of the plant being grown. When presenting the study overview to the students, the researcher asked how many of them had every studied anything about plants at school or at home. One student commented that “He had helped his grandmother plant some of her garden once.” Another student told me, “My mom made me help plant some flowers.” No one could remember ever studying anything about plants in school.

**Pre- and Posttests**

The pre- and posttests (Appendix H) were administered on the first and last days of the study respectively. The students followed the directions easily and there were no questions from either group. The students did comment after the test about how hard they thought it was. One student commented that “I didn’t know you could ask that many questions about a plant.”

The posttest was a rearrangement of the pretest with changes made to eliminate pretest recall as a factor. Since the test was a combination of 20 multiple choice and eight matching questions, each type of question had to be rearranged separately. The same answers were used for each multiple choice question with their order changed. The next step was to change the order of the first 20 multiple choice questions. The last part of the test involved the student matching plant organs with their functions. The same image was used but the order and labeling of the functions to be match were rearranged.

All quantitative data collected were analyzed using SPSS software. The techniques used included both individual group and combined group analysis. The first tests run were paired t-tests. The null hypothesis stated that no significant difference existed between the pre- and
posttest results. Three separate tests were conducted to determine if the significance was the same for the individual group results and the combined results. The results of these tests, shown in Table 6, indicate that there was a significant increase in the test scores whether when analyzed individually or combined. The null hypothesis was rejected and the alternate hypothesis which states that a significant difference existed was accepted.

Table 6
Paired t-Test Group and Composite Pre- and Posttests

<table>
<thead>
<tr>
<th>Category</th>
<th>Control</th>
<th>Treatment</th>
<th>Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>-7.571</td>
<td>-7.435</td>
<td>-7.500</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>4.411</td>
<td>4.121</td>
<td>4.212</td>
</tr>
<tr>
<td>Std. Error of Mean</td>
<td>0.963</td>
<td>0.859</td>
<td>0.635</td>
</tr>
<tr>
<td>t</td>
<td>-7.866</td>
<td>-8.652</td>
<td>-11.801</td>
</tr>
<tr>
<td>df</td>
<td>20.000</td>
<td>22.000</td>
<td>43.000</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Since the paired t-test shown a significant increase in test scores, an independent t-test was run to determine if a significant difference existed between the mean difference of the control and treatment groups. The null hypothesis stated that a significant difference did not exist. The results of the test, show in Table 7, indicated that a significant difference did not exist and therefore the null hypothesis was accepted.

The possibility of running an analysis of covariance (ANCOVA) was considered prior to the research but not run when the independent t-test showed no significant differences in the iLEAP scores. Running the independent t-test on the pre- and posttest difference was preferred.
over the analysis of variance (ANOVA) since only two groups existed. When there are only two groups the ANOVA is mathematically the same as running the independent t-test. The negative t scores in the paired t-test indicate that the posttest scores were larger than the pretest scores since it was a pretest minus posttest analysis.

Table 7
Independent t-Test of Difference Between Pre- and Posttest Scores

<table>
<thead>
<tr>
<th>Levene’s Test for Equality of Variance</th>
<th>t-test for equality of means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
</tr>
<tr>
<td>Equal variance</td>
<td>.007</td>
</tr>
<tr>
<td>Assumed</td>
<td></td>
</tr>
<tr>
<td>Equal variances</td>
<td></td>
</tr>
<tr>
<td>Not assumed</td>
<td></td>
</tr>
</tbody>
</table>

Pre and Post Attitudinal Surveys

The pre and post attitudinal surveys were administered directly following the pre- and posttests. This was the first time that any of the students had completed a survey of this nature. A thorough explanation of the directions was given after the survey was distributed but the students still had a problem understanding the semantic differential scale. After several examples were given the students proceeded with the survey. Before giving the post attitudinal survey there was only one student with a question and again it referred to the semantic differential scale.
Two paired t-tests were run on the pre and post attitudinal results. The null hypothesis for both tests was that no significant difference existed between the means. The first analyzed both the Likert and semantic type questions together while the second did an analysis of the Likert and semantic type questions separately. The results, as shown in Table 8, show that no significant difference existed between the means when the survey questions were analyzed in the composite form. The null hypothesis was accepted for that analysis. When the results were analyzed using a separation of question types the results were mixed. The analysis of the semantic questions agreed with the composite results that no significant difference existed and the null hypothesis was accepted for those questions. A different conclusion occurs when we analyzed just the Likert-type questions. These results show a significant difference in the control and treatment group scores, therefore the null hypothesis was rejected.

**Equipment**

There was no instruction given to the control group and any equipment used was done so by the researcher or the instructor. The instructions for the treatment group were conducted with no difficulties encountered and a minimal number of questions. Only five of the students had no previous experience using a digital camera. The main task with still imaging was showing the students where to locate the features they would be using on the available cameras. The students’ knowledge of time-lapse photography was non-existent. Before setting the camera to take a time-lapse sequence, a brief overview of time-lapse imaging and its uses were discussed. Each subgroup had the opportunity to take their own time-lapse images and view the sequence on the camera display screen as a mini-movie.

Each group was also given instruction on using the ProScope™ and the taking and storage of images using this hand-held digital microscope. The ProScope™ has changeable
lenses and the students were apprehensive about changing them. They quickly got over their anxiety with a little encouragement.

Table 8

Grouped and Composite Pre and Post Attitudinal Survey Paired t-Test

<table>
<thead>
<tr>
<th>Category</th>
<th>Likert</th>
<th></th>
<th>Semantic</th>
<th></th>
<th>Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Treatment</td>
<td>Control</td>
<td>Treatment</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>-2.476</td>
<td>-4.652</td>
<td>-0.870</td>
<td>-0.18595</td>
<td></td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>6.780</td>
<td>5.556</td>
<td>3.647</td>
<td>0.44878</td>
<td></td>
</tr>
<tr>
<td>Std. Error of Mean</td>
<td>1.479</td>
<td>.760</td>
<td>1.194</td>
<td>0.760</td>
<td>0.06766</td>
</tr>
<tr>
<td>t</td>
<td>-1.674</td>
<td>-4.015</td>
<td>0.359</td>
<td>-1.143</td>
<td>-2.748</td>
</tr>
<tr>
<td>df</td>
<td>20</td>
<td>22</td>
<td>20</td>
<td>22</td>
<td>43</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.110</td>
<td>0.001</td>
<td>0.723</td>
<td>0.265</td>
<td>0.009</td>
</tr>
</tbody>
</table>

The use of the DigiScope™ was a little more challenging since they needed to perform a calibration before they could use its measuring capabilities. The students preferred the ProScope™ and had a tendency to use it over the DigiScope™ whenever possible.

The final technique to which the treatment group was introduced to was the taking of stroboscopic images. To successfully capture a falling object that is also rotating at various stages of rotation on a single image requires understanding of the phenomenon and proper team coordination. Each group practiced with a swinging pendulum before attempting to film the falling rotor. Each group was successful in accomplishing the procedure.

Bulbs and Plants

The planting of the amaryllis bulbs by both groups started on the third day of the study and continued until all of the bulbs were planted and cared for by assigned group members.
When the additional amaryllis bulbs were found, each student was given a bulb to plant and care for. These additional plants were taken home by the students prior to the Thanksgiving break in 2006.

The rate of growth of the amaryllis plants was slower than expected. Normally bulbs from the Netherlands can be forced to bloom in four to five weeks and the African bulbs in six to seven weeks. The bulbs had been taken out of refrigeration two weeks prior to their planting but they were not growing at rates previously experienced. As is usually the case, the scapes (leafless stalks that develop in the bulb and terminate with the flower cluster) developed first followed by the growth of leaves. It is not uncommon in some varieties for the leaves to develop after the scapes have reached a height of 6 to 12 inches. The plants used in this study had leaf growth rates slower than experienced in field studies. Some of the bract and scapes reached a height of 24-30 inches without appreciable leaf growth (Appendix N). The original plan called for the students to observe and collect data on the growth characteristics of the amaryllis leaves. The leaves were to be stamped with a non-toxic ink followed by the students observing and measuring the horizontal and vertical leaf growth with the aid of the digital microscopic. The plan also called for the treatment group to take time-lapse images of this growth. During the allotted time for the research, the leaves did not grow to a sufficient size to stamp, measure, or produce meaningful time-lapse images.

Every student in both groups had the opportunity to participate in the dissection of a daylily when their class went to the science laboratory. This was the first time any of the students had been in a school science lab. Each subgroup was given directions on the dissection procedure and asked to keep careful notes on what they did and observed. The treatment group was instructed to document the dissection and observations with pictures. The comments from both
groups were positive on this activity. A ProScope™ was set up during both classes. The researcher used the scope to provide the control group participants the opportunity to investigate their plants at a microscopic level. The treatment group was given the option of using the ProScope™ to take images. One student commented that “this is the best science class I ever had. We got to do a lot today and it was fun. I learned a lot.” Another student said “I hope we come back to the lab it is fun. We got to cut the flower up and find what we had been talking about.” There were no negative comments from any participant.

The mandevilla plant remained in the classroom for 5 weeks. The control group paid very little attention to the plant while the treatment group would often examine it when studying the structure and function of the plant organs. There were over 100 pictures taken of the mandevilla.

The planting of a bulb was a new experience for the vast majority of the students. Both groups were excited about their plants and their journals reflected their enthusiasm. One student wrote, “I planted my first real plant today. It is neat to know you helped something that was alive get a start.” Another student stated, “I never did this before. I hope it grows.” A third student commented, “I followed Mr. Lou’s directions. I think I see a plant coming out already. Maybe I’ll have the first flower.” The students got very excited when the science teacher said that they may be planting a seventh-grade flower bed in the spring. Images of the plants taken by the treatment group can be found in Appendix O.

During week 5 of the study the plants had to be moved from the classroom to the science lab during a 5-day school break. This move was necessitated due to the waxing of the floors. Since the school was undergoing final construction at the beginning of the academic year the floors had not received their protective wax. The school board scheduled the waxing for this time period.
**Control Group Images**

The control group was given pre-existing images of each plant organ as it was introduced. The students were told that the images were theirs to keep and that they could write on them if they wanted to. Throughout the study the researcher would find these pictures on the floor, in the trash, and on classroom shelves. Seven of the field notebooks contained the images when they were turned in at the end of the study.

When asked if the images were useful the answers varied between “not really” “sometimes.”, and an unenthusiastic “yes”. The researcher had noted on several occasions that the students had a “very short attention span when looking at the images” and “they just glanced at the image”. The way that the students viewed the images gave the impression that there was no analytical intent in their action. It appeared that the pictures were just something to look at and not learn from.

During the viewings of *The Private Life of Plants* (Attenborough, 1995) the students were fascinated and attentive at first, but then lost interest with heads going down on the desks and four students closing their eyes. Comments on the film indicated a short attention span when viewing this type movie. Some examples of this were: “this was o.k. for a few minutes but then it got boring”, “we watched a movie on just plants today”, and “the movie was o.k. but too long.” There were only three students who found the entire movie clips very interesting. One commented that “I’ve never seem anything like this before. It showed me how seeds get away from the mother plant and some ways are really weird.” There were many students who were neutral in their feelings for the movies. These students paid attention but never appeared excited about anything they were watching except something they considered “gross.” An example of
this was a form of natural seed dispersal in which seeds were consumed by a rhino and later deposited via dung.

Comments such as “the plants need the birds and insects to make sure their pollen gets to other plants”, “some things steal the nectar without carrying the pollen, this is not good and this is not good for plants”, and “some plants need special pollinators to get the nectar and the pollen so they can spread it.” demonstrated the students’ understanding of the importance of pollinators and the mutual benefit that must exist between plants and pollinators. Questioning on the dynamic relationship of plants and their pollinators reaped immediate response from the students, with very few wrong responses. Although the control group participants understood the mechanics and importance of insect pollination, only two or 9.5% of them knew how to calculate the frequency of pollinator visits using pre-existing time-lapse images. In casual conversations with some of the students, the researcher found out many of them did not realize that the total time frame could be calculated knowing the number of individual images and the time interval between each image.

**Treatment Group Images**

Almost 4,000 pictures were taken by the treatment group during the study. The only restrictions placed on the images were those that pertained to the anonymity of the participants. The images included still, time-lapse, and stroboscopic types. Over half of the images taken were time-lapse. With four time-lapse cameras set to take a picture every hour, almost 100 images were made daily using just this technique. Not counting still images using a high speed flash or strobe light, the least number of pictures made was stroboscopic. There were a total of 112 images made by the students in a dark room and a flashing strobe light. The remaining images were still pictures taken with and without the aid of a flash.
In the beginning, watching the students take the pictures was like seeing a mixture of opposing opinions, techniques, and scientific curiosity levels collide. The first task was for the groups to develop an agreeable plan by which the task would be accomplished. The second step involved was the division of responsibilities, and the final task was to decide how technical the results should be. Most of these issues were addressed by the small groups during the initial activities on how to use the imaging equipment.

When students were seen working individually and not with their group, the researcher would casually question them on why they were doing things by themselves. It was important to probe the student for a reason because what appeared to be an individual working by themselves may be part of the group activity. An example of this is when the researcher approached a young lady who had picked up one of the extra cameras and was photographing the mandevilla plant. When the researcher talked to her, he found out that the group had divided the tasks so they could accomplish more in the time remaining.

Positive feedback on cameras usage started with the first investigation. Ninety-one percent of the students recorded positive comments on using the camera during the lesson. The nine percent that wrote negative comments were upset over the limited time each individual had using the camera. Positive comments included the statements: “I liked taking the pictures of the plants. Its cool how a plant grows.” and “I like making my own pictures, this way I get what I need to see.” Another student commented “the pictures can help me remember what I saw. They are better than taking notes.” One negative comment was that “my time using the camera was not to [sic] long. It takes to long for people to get what they want in the picture.” Over the course of the study 100 percent of the treatment group made a positive comment on the use of the camera. With the sharing of equipment, the individual comments fluctuated according to the role the
participant played in each activity. Patton (2002) emphasized the role of patterns in qualitative analysis and the rereading of data to search for these patterns. A common component of the positive comments was when the participant felt a part of the imaging process. This was often evidenced by the words “when I” or “when we” in the comments. A student wrote the following as the final entry in their field notebook:

“My opinion about taking the pictures was that it was so awesome using cameras. It helped me understand it more. The pictures that I took were really good. I think it helped me very much. That is my opinion.”

As the study progressed, two trends became evident. The extra cameras were rarely idle when the activity involved taking pictures and the equipment was being shared both within and between the groups. The researcher observed an individual who had one of the extra cameras ask if anyone else needed to use it since he has already taken some extra shots. When no one needed the camera he smiled, sat on the floor, and went back to taking pictures of a mandevilla flower. On two occasions the researcher noticed a student who seemed to shy away from the group and took very few pictures. The opportunity to talk to her came when the researcher found her by herself, looking for something in her notes. He made a friendly comment about her being “reverse” camera shy since it appeared she didn’t seem to like taking pictures. She told the researcher that one of her group made fun of her during the lesson on using the equipment. She made a mistake and erased an image when viewing it. Despite efforts to get her more involved, the researcher saw very little change in the number of pictures she personally took.

Samples of the still and stroboscopic images made by the treatment group can be found in Appendix O. Since each subgroup was assigned their own camera, it was easy to maintain separate group folders with the researcher downloading the images from each camera into the
appropriate folder. In discussions with the students, it was discovered that 82.6% of the students had used the extra cameras to take pictures. Some said it was so they “could take the pictures they wanted”. One student made a profound comment when he said that “It’s like writing a story about the flower without having to use words.” The images from the extra cameras were downloaded into a separate folder. During the study the student had the opportunity to view there images on both the computer and on hard copies. Poor quality images were deleted from the folders. Wallet-sized hard copies of the images were reproduced 35 to a sheet for student use.

During the dissection of the daylilies, the students took pictures of the dissection process and their discoveries. The images included ones made using the ProScope™ as well as the digital cameras. The students were so engrossed in looking at the various structures on the computer screen that they often forgot to take a picture of what they viewing. The researcher had to remind groups to capture what they saw on the screen. When observing each small group use the ProScope™ to take images the researcher heard the comment that their school “needed one of these.” The quality of some images was diminished due to the motion created by students trying to use the devise to explore and take pictures at the same time.

Stroboscopic imaging was used to understand the natural aerodynamics used by some seeds to increase their dispersal radius. This type of imaging is utilized to either capture multiple phases of an object in motion or to create the visual appearance of the object being motionless. This type of imaging is conducted in a darkened environment and requires the synchronization of multiple flashes, the opening of a camera shutter, and the moving object to be photographed.

The students were taken four at a time into the “black room” assembled inside their normal science classroom. Each group was instructed in the method to be used for the imaging session. Since the researcher had previously explained the concepts surrounding the theory and
usage of stroboscopic imaging, it was not necessary to repeat it. The students were each given a roll in the process and a pendulum was set up for them to practice with. A pendulum was used since it is easier to photograph an object that has restricted movement, as opposed to the unrestricted movement of the falling rotor. Each group was allowed to make as many test runs with the pendulum as they deemed necessary. The group looked at the image they produced after each trial.

The practice trials were followed by the dropping of the Rotor Motor which modeled the motion produced by the fall tree seeds. From previous experience, the researcher had learned to have a small fan running in the “black room” blowing slightly upward toward the falling rotor. Without this air circulation the rotor would not rotate before hitting the ground. The researcher had experimented with photographing an actual Boxelder (*Acer negundo*) seed and the results were poor due to their small size and color. The equipment needed to produce good images was too expensive for the average school to acquire. The Rotor Motor activity was successful with an ordinary digital camera and a $12 WalMart strobe light. Each group was again allowed multiple attempts until they obtained the desired results. The most repetitions required to get a successful image was four.

The reaction of the students to this modeling was incredible. The only negative reaction came from a student who was claustrophobic. We handled the situation by allowing her to stand by the door with the flap slightly ajar. Normally it is closed with a battery operated lantern providing the light needed for setup. When everything was ready she would close the flat and the imaging process began.

The comments by the students, teacher, and the school technology coordinator, who came to observe the activity, were extremely positive. The excitement started when the students
entered the room and first saw the 5 ½ ft wide by 8 ½ ft long by 5 1/22 ft high structure covered with black. The students began making comments such as “Oh neat”, “wow”, and “look at that” to each other immediately. The excitement continued throughout the activity with comments being made every time a group exited the structure. One of the high school teachers commented to the researcher later that day that everyone in the school has heard about the “black room” and how much the students enjoyed it.

When the students were asked about the activity one quickly mentioned that their images were similar to the ones seen in the Attenborough (1995) film clips. They even knew that the film images were slow motion images and that they didn’t “stop” in the air like the images they just took.

There was a visible difference when the treatment group watched clips from The Private Life of Plants (Attenborough, 1995) as compared to the control group. Although these students were similar to the control group students in the decline in interest during the last part of the clips, the increased intensity with which they watched the movie was obvious. You could see facial expression change with changing scene. Little comments would slip out during the viewing. Some of the more notable comments recorded were: “I hope we can see all of this”, “I won’t get mad at my dog when he gets stickers again, it’s meant to be.”, and “This is awesome.” One student told the person next to him “We know how to do that.” This was in reference to the time-lapse imaging being used in the movie clip. The word bored was never heard from the group, but one student did manage to take a nap.

The time-lapse imaging was hampered by several problems. The amaryllis leaf growth rate was too slow for the planned leaf growth study using time-lapse imaging. In checking with the students two months after the study, 60 % said their plants bloomed and died with little or no
leaf growth, 31% reported significant leaf growth after the flower bloomed, and 9% stated that their leaves grew at the same time the scapes were elongating.

The process of taking time-lapse images of the growing amaryllis also included challenges. The two plants being grown in the classroom grew at an unusually slow rate. This was further complicated by the power to the school being occasionally turned off to facilitate final construction activities. Another challenge occurred when we were informed that all of the classrooms were to be emptied during a 5-day school break so the floors could receive their initial waxing.

Prior to the 5-day break, all of the time-lapse equipment was moved to the science lab and placed on counter tops so the time-lapse process would continue. The bract was just starting to open on the plant with the best growth rate. During the break, the power was lost to the lab and the opening of the bloom was not recorded. The second classroom plant dedicated to the time-lapse segment of the study did not bloom until three weeks after the study ended.

Knowing the uncertain nature of plant growth from previous experience, the researcher had provided a backup to the time-lapse imaging. Two students from the treatment group were selected to conduct the identical process in their homes. The parents of these students were contacted and permission was given for them to conduct the imaging at home. One of amaryllis plants photographed at home was also incomplete. It only reached a height of about six inches by the end of the study. The forth amaryllis dedicated to the time-lapse process was a success. The bulb started slow but then grew at a reasonable rate. The time-lapse images captured the initial stages of the plant coming out of dormancy, the opening of four flowers, and the death of the flowers. The second bulb was a complete success. The plant grew, the flower bloomed, and then the flower died. The class was instructed in the use of Constructor Package 6.2 (Caracena, 2000)
software and the acquired time-lapse images were converted to an AVI formatted movie. The students fine tunned the movies’ visual qualities by using the speed adjustment program to regulate the number of frames per second shown. The final movie was set to run at 25 frames per second.

Even with the multiple problems encountered, the students showed beneficial effects from the learning experience. An understanding of the concept of visual time compression was evidenced by comments made throughout the study. In the interviews at the end of the study, 100% of the treatment group participants interviewed knew that time-lapse photography was used to produce the opening sequences of *The Private Life of Plants* (Attenborough, 1995). In comparison, 100% of the control group participants interviewed gave a wrong answer. In a discussion with the treatment group after finalizing their movie, the group was asked how they could tell if what they were watching may have been made using time-lapse photography. One young girl quickly answered “it could have tiny flickers, a jerky motion, or its happening too fast to be real”. One of the students made the comment that “Making time-lapse movies is like having a set of those little cards and flipping them real quick. How fast you flip makes a difference on how it looks.” About 57% of the treatment group knew how to use pre-existing time-lapse images to calculate the frequency of pollinator visits. Only three of the students did not equate the number of images with the elapsed time. The others had problems with the math.

**Posters**

Although there was a total of ten groups in the study, a total of 12 posters were produced. Two of the treatment groups used poster boards left over from the science fair and constructed a second poster. The posters were analyzed by placing them in a large circle with the researcher in the middle. Using Patton’s (2002) emphasis on pattern recognition, the panorama was then repeatedly scanned for patterns of similarities and differences.
The most obvious similarity was in the use of decorations. Tufte (1990) makes references to “chartjunk” and how it is used by individuals who think data are dull and boring. The researcher thinks the birth of “chartjunk” is “posterjunk.” The time allocated to creating a visual explanation of understanding was squandered by five groups on the creation of poster decorations. When talking with students, the researcher discovered an almost universal belief that the most attractive project gets the best grade. The belief that appearance is more important than content was brought out by 90% of the students questioned. The other 10% felt that it was a combination of looks and content. No one professed content as being the most important element. One student gave an analogy when he said, “It’s like they tell you. It’s not what you say. It’s how you say it.”

The control group posters contained a total of 11 mistakes in the written descriptions of the pictured organ’s function while the treatment group posters only contained 1. The control group had three additional images with no mention of the organ’s function. When looking for mistakes, the researcher realized that on nine posters many of the functions were stated as incomplete sentences. The sentence structure, vocabulary usage, and grammar caused the researcher to question if poor written communication skills hindered the students in stating what they knew.

No control group poster and only two treatment group posters showed a relationship between the individual organs and the whole plant. One of the posters used the yarn provided to show their organs location on the plant. The other poster arranged them around the edge of the poster relative to their position on the whole plant.

Field Notebooks

Every participant was issued a field notebook on the first day of the study along with a guide to using them (Appendix J). The notebooks were distributed at the beginning of each class.
and collected at the end and although the students were asked to write comments about each day’s lesson, no student entered comments every day of the study. Both the teacher and researcher constantly reminded them to enter comments as well as content notes and observations. Some of the daily comments consisted of one sentence while others were paragraphs. On the last day, the participants were asked to write a brief summary of their experiences during the study.

The possibility of using Atlas.ti (Muhr, 2002) qualitative software to analyze the participant comments was considered. After taking into consideration the time required to enter all of the qualitative data into the computer, the idea was abandoned.

The daily comments were read and divided into quotes that represented separate thoughts. Each thought was assigned a code or theme. The first time a new theme was identified it was given a name and added to the list of themes. A list of the codes, their definitions, and examples of quotes given each code can be found in Appendix Q. The notes that were considered content notes were not coded and included in the analysis. These included such items as definitions, procedures, and general content information.

The themes that emerged most frequently were those involving the acquisition of knowledge, the assumption of increased understanding accredited to taking pictures, and having fun experiencing while learning. Table 9 shows the final list of themes and the frequency of occurrences. The frequencies are tabulated and listed according to the group affiliation of the participant making the statement.

When gathering the data the following patterns were noted: a) every participant commented on learning new material, b) all of the comments on being bored were made by four students in the control group and 3 students in the treatment group, c) the comments on the help received from images by the treatment group participants referred to the taking of images as well
as observing their images, d) the hands-on activities for the control group were made in reference to the plant dissections and the planting of the bulbs, and e) the hands-on activities for the treatment group made reference to the plant dissections, planting of the bulbs, and various activities related to taking the images. The table of themes and frequencies was recalculated, as shown in Table 10, to show the average number of comments per group participant for each theme.

Table 9
List of Code/Themes and Frequency by Group

<table>
<thead>
<tr>
<th>Code/Theme</th>
<th>Control Group Frequency</th>
<th>Treatment Group Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased Knowledge</td>
<td>57</td>
<td>81</td>
</tr>
<tr>
<td>Fun</td>
<td>32</td>
<td>58</td>
</tr>
<tr>
<td>New Experience</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>Question Generator</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Boring</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Plant Hater</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Images Helped</td>
<td>0</td>
<td>103</td>
</tr>
<tr>
<td>Group Lover</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Hands-On</td>
<td>32</td>
<td>47</td>
</tr>
</tbody>
</table>

The regular classroom teacher also maintained a notebook of observations and comments. The written notes were augmented with visual documentation in the form of still images taken by the teacher throughout the study. The images captured the study from an observer’s vantage point. The images provide the research with a means of postactivity contemplation and
evaluation. Since the images are of the participating students involved in various stages of the study, they can not be shared in this report to preserve student anonymity. The teacher comments, coupled with the teacher-as-observer images, were an excellent means of providing feedback to the researcher.

Table 10

<table>
<thead>
<tr>
<th>Code/Theme</th>
<th>Control Group Average Frequency</th>
<th>Treatment Group Average Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased Knowledge</td>
<td>2.7</td>
<td>3.5</td>
</tr>
<tr>
<td>Fun</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>New Experience</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Question Generator</td>
<td>0.1</td>
<td>0.57</td>
</tr>
<tr>
<td>Boring</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Plant Hater</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Images Helped</td>
<td>0.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Group Lover</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Hands-On</td>
<td>1.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The teacher’s notes focused on instructional techniques, student engagement, and group activities. The comments indicated the students in both the control and treatment groups were actively engaged in the lessons with one exception. The teacher commented that in both classes the students “were involved” in the video at the beginning then “started losing focus” toward the end of the clip. Repeated references were made regarding the researcher asking “leading
questions” and the students being “able to correctly respond.” Comments on group activities were limited to the type of activity and the level of student engagement. The teachers comments were brief and to the point with the majority being procedural comments.

The teacher took a total of 60 pictures during the study with 57 being group activities and 3 showing researcher lead demonstrations. The images provided addition support to the teacher’s comments regarding student engagement during both discussion and small group activities. The images also provided a means of visually reviewing and contrasting the individual versus group involvement. There were no visual indicators of any individual participators not being engaged during small group activities.

The researcher maintained field notes during the study. As soon as possible after each lesson comments on the day’s activities were recorded. The notes included significant comments or actions by the participants, comments on student behavior and engagement, areas of concern, and indicators of either instructional success or failure. Personal notes were often added to maintain a record of the intuitive feelings associated the daily and overall progress based on extensive classroom experience.

The researcher’s notes agreed with those of the teacher in respect to student engagement in classroom activities. They also agreed on the willingness of the students to participate in the class discussion and attempt to answer challenging questions. Although both groups had a high level of engagement in the lesson, the researcher had noted on different occasions a difference in the excitement level of the two groups. The treatment group appeared much more eager to get started and possessed a higher energy level. Another pattern found was the comments involving students’ asking questions. There were only two days that the questions asked by the control group participants were worthy of comment. On the other hand, the questions asked by the
treatment group were worthy of comment on 11 of the 13 days. The notable questions by the control group occurred on the day the amaryllis bulb was dissected and the day they dissected the daylily. A treatment group student was taking pictures of the Mandevilla plant on the day we discussed the metamorphic process associated with plants. He asked, “If I cut it where the two parts meet which part would it be?” After studying images of plants and their pollinators a young lady in the treatment group asked, “If I set my camera up to take pictures of pollinators and none come, what does it mean?” The asking of good questions by the treatment group was one of the major differences noted by the researcher. The researcher also noted the discarding of control group images by the end of the class.

**Interviews**

Each student participating in the interviews was not told of his/her selection until just before the interviews started. The Researcher used the same classroom used in the lesson to conduct private interviews. The students were reminded the rules of anonymity that applied to any comments they made. All of the students appeared to be comfortable with the interview. When the student finished the interview they went immediately to their physical education class.

When asked their overall opinion of the lessons, 100% of the students responded in a positive manner. The students described them as awesome, neat, fun, exciting, and different. All 10 students also mentioned planting their own bulbs as an exciting moment. There was also unanimous agreement that they learned something from the lessons. Two of the control group students said they didn’t like it that the other group got to use the cameras and they didn’t. They knew it was part of the study but said that when they talked to their friends in the other class they talked about taking the pictures. There was no hesitation on the part of nine students in giving or elaborating on there opinion of the lessons. The 10th student was from the control group. He
started to answer and then stopped. After a moment he said, “I know I learned a lot. I didn’t know anything about flowers. I though that when the bee visited the plant he fertilized the plant you know like people do.” He actually believed that the bee was having sex with the plant.

The differences began to appear when the students were asked about the role of images in the process and if they thought they affected their learning. The comments from the control group students ranked their helpfulness from a low of “not much” to a high of “pretty much.” When the student were asked how the images helped them understand plants the answers included “They allow you to see inside without cutting it up.”, “Pictures help you study for a test.”, and “They let you see what was being talked about.”

The responses from the treatment group were different. The students talked about using the images to understand the various parts, how they were connected, and what they did. One student commented that “Taking the pictures made me think about the part I was looking for. It also helped me remember it.” Another student made the statement “You can use pictures to record what is happening when you are not looking and see it later.” All five of the treatment group students gave numerous examples of how the images affected learning. All five also stated that taking the pictures made them different and increased their interest in what was being studied.

Each of the participants interviewed was reminded of the opening scenes found in the introduction to *The Private Life of Plants* (Attenborough, 1995). They were asked to tell the researcher how they thought they were made. All five of the control group student answered incorrectly. The all believed that a regular movie camera was turned on and left to run for a very long time then the parts of the film they didn’t want to see were cut out and the remaining film is what we saw in the movie clip. Not one of them had any idea about time-lapse photograph. The
researcher asked them if they had ever seen movies on TV where the clouds go by quickly and it goes from day to night in a very short time. They all gave the same answer as before. When the five students from the treatment group were asked same question on the opening scenes, every one of them answered correctly without any hesitation.

The control group students did a little guessing when asked about the use of various photographic techniques by scientist. One student said that all he knew was that they took pictures to show what you are studying, one made reference to the scientist using them to make a scrapbook of the experiment, and another was said them helped them understand what they were studying. No one from the control group even tried to give an answer for how scientists would use stroboscopic imaging. Four of the treatment group had no problem giving examples of how scientists would use all three photographic techniques. The fifth student had no problem giving examples for time-lapse and stroboscopic imaging but drew a blank on the use of high speed techniques.

Each student was asked the following question at the end of the interview. “If you had to change one thing about this study, what would it be?” The student replies are shown in Table 11.

The teacher and researcher talked throughout the study. The discussions allowed the researcher to compare his thoughts and observations with those of the teacher. Feedback was sought on such topics as student engagement, student and parental feedback, and noticeable differences in the classes. At the end of the study the final question asked the teacher was the same one he asked the students interviewed.

The teacher had received no negative feedback from students, parents, or administrators. He felt that the treatment group was more excited about the lessons and participated at a higher level. He liked the hands-on activities and felt that everything was appropriate for these students.
Table 11
Type and Frequency of Responses to Final Interview Question

<table>
<thead>
<tr>
<th>Response</th>
<th>Group</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>More time in the science lab.</td>
<td>Control</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>2</td>
</tr>
<tr>
<td>More hands-on activities</td>
<td>Control</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>1</td>
</tr>
<tr>
<td>Everyone allowed to take pictures</td>
<td>Control</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>2</td>
</tr>
</tbody>
</table>

The lack of a good science background was discussed on several occasions with the teacher and researcher in total agreement on their deficiency in content knowledge. Other areas of concern included poor writing skills which hampered the student’s ability to communicate their scientific knowledge. The notebooks were evidence of poor writing skills.

In addition to the participating science teacher, informal feedback was provided by other teachers and school administrators. Since the students remain with the same class all day, other teacher heard comments from both groups. One teacher told the researcher that she didn’t know what they were doing with those cameras but they were sure excited about it. Another teacher told the researcher that the study had affected some pedagogical practices in other rooms. Two teachers talked to the researcher about using cameras with their classes. The researcher was leaving a store down the road from the school when two ladies stopped the researcher and told him they had children in the science classes I was teaching. One mother said that her child was in...
the class taking the pictures and that her son would come home excited and tell her all about it. The other women’s child was in the control class. They both thanked me because they said their children were enjoying it. Data comes in many forms and from many directions.

Questions

- **Question 1:** Will time-lapse and stroboscopic photography enhance student understanding of a plant’s interactive structure?

  Although a significant increase in test scores was indicated by quantitative analysis, there was no significant difference between the mean difference of the control and treatment groups using the results from all questions. The test results where separated into subtest scores according to question relevance. This facilitated the running of an independent t-test on the structure and function subtest scores. The results, as shown in Table 12, indicate no significant in the mean difference for these subtest scores.

Table 12

Independent t-Test of Difference Between Pre- and Postsubtest Scores: Structure and Function

<table>
<thead>
<tr>
<th>Levene’s Test for Equality of Variance</th>
<th>t-test for equality of means</th>
<th>Mean Difference</th>
<th>Std. Error Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig</td>
<td>t</td>
</tr>
<tr>
<td>Equal variance Assumed</td>
<td>.747</td>
<td>.392</td>
<td>-.528</td>
</tr>
<tr>
<td></td>
<td>-.532</td>
<td>41.808</td>
<td>.598</td>
</tr>
<tr>
<td>Equal variances Not assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The test instrument may not have been able to differentiate the students’ learning on the aspects the qualitative study examined, plus, the fact that the treatment group test scores were not lowered by the image-making activities shows the additional benefits. An analysis of the various qualitative data sources shows patterns that may be indicators of differences in the understanding of a plant’s interactive structure. Two of the treatment group posters were designed around the structure of the whole plant while none of the control group posters displayed this type of pattern. Control group posters contained 11 images of plant organs that had the incorrect organ function written in the description while the treatment group poster only had one.

Both the teacher and researcher had noted that the images distributed to the control group students were often discarded by the end of the class on the floor. The students glanced at the images as opposed to studying them. Neither the teacher nor the researcher had made mention of any higher order questions regarding structure and function originating from the control group. In contrast, the treatment group was excited about the images and studied the images after they took them. The treatment group students were given copies of the images they took and not one copy was found discarded in the classroom or around the school. The treatment group students commented that the images help them understand the structure and function of the various organs.

- **Question 2:** Will time-lapse and stroboscopic photography enhance student understanding of plant reproduction?

Although a significant increase in test scores was indicated by quantitative analysis, there was no significant difference between the mean difference of the control and treatment groups using the results from all questions. The test results were separated into subtest scores according to question relevance. This facilitated the running of an independent t-test on the reproduction
subtest scores. The results, as shown in Table 13, indicate no significance in the mean difference for these subtest scores.

The qualitative data collected showed no pattern of differences between the control and treatment groups regarding the understanding of the basic concepts of plant reproduction. The level of engagement by all participants during the dissection of the daylily flowers showed no distinguishing patterns. There was however, a difference noted in the behavior of the students after the actual dissection was finished and the parts were arranged on their cloth backgrounds.

Table 13

<table>
<thead>
<tr>
<th>Levene’s Test for Equality of Variance</th>
<th>t-test for equality of means</th>
<th>Std. Error Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal variance Assumed</td>
<td>t-test for equality of means</td>
<td>Std. Error Difference</td>
</tr>
<tr>
<td>F</td>
<td>t</td>
<td>Df</td>
</tr>
<tr>
<td>1.534</td>
<td>.338</td>
<td>42</td>
</tr>
<tr>
<td>Equal variances Not assumed</td>
<td>.341</td>
<td>41.519</td>
</tr>
</tbody>
</table>

The original excitement and fascination observed in the control group students disappeared almost immediately following the dissection with the all but one group getting off task. The treatment group continued examining parts after the dissection and taking images after the dissection with the same level of engagement noted during the dissection. The treatment groups took additional images using the ProScope™. Every group was excited about seeing pollen under the scope. The images acted as a catalyst for further discussion.
• **Question 3:** Will the process of taking an image enhance student learning?

While the quantitative data indicates the taking of images has no significant impact, the qualitative data indicates it does have an impact. The students believe that it made a difference and they are the learners. This pattern of belief was expressed in oral comments during the classes and in the interview and in written comments in their filed notes during times of reflection. The comments on the levels of engagement, excitement, and awe by the treatment group also provided data which supports this assumption. The data showed that the students taking images remained on task longer in a laboratory situation, asked questions that indicated depth of inquiry, and showed more interest in the class.

• **Question 4:** Will the understanding of photographic techniques enhance a student’s conceptual understanding of scientific information given in image format?

The interview question pertaining to the making of *The Private Life of Plants* (Attenborough, 1995) clearly indicates the difference between students who understand the techniques used in recording a phenomenon and those who do not. The treatment student knew that action was being documented at prescribed intervals and the show was like animated flip cards. The control participants thought the video was being shown faster. The comment by the treatment student expressing his knowledge of how a scene was made is an indicator prior experience that will be used to interpret what is being seen. During the study students would take an image that when viewed would not have the same color as what was photographed. When the students asked what was wrong with the camera, we discussed the fact that different light sources have different effects on the color you see on the photograph. A student asked how they would know if what they were looking at was the real color. The researcher informed him that is why we question what we see and not take it as the truth without proof. Those students who did not take images did not have any reason to ask this question.
SUMMARY AND CONCLUSION

Historical Aspects

For over 30,000 years humans have created images that depict what they see, what they think they sees, how something works, and how they would like it to work. The only limit to the use of images is the limit of human imagination. Robin (1992) stated that each scientific image served a unique purpose and that all scientific images could be put into one of six distinct categories: observation, induction, methodology, self-illuminating phenomena, classification, and conceptualization. The cave drawings found in the Chauvet Caves of France and the latest digital images returned from Mars have the same source: human imagination.

Technology and Scientific Imaging

The needs of Robin’s six categories were driving forces that stimulated the creative imaginations of scientists like Talbot, Daguerre, Ott, and Edgerton. Unusual events provided purpose and opportunity to develop innovative imaging techniques. A bet on how the legs of a horse move when galloping, helped develop sequential imaging and help spur the interest in motion pictures. Sadly, the D-Day invasion and the testing of an atomic bomb provided the purpose, opportunity, and financial support needed to further develop stroboscopic and extreme high speed photography. The current digital mania by consumers has provided financial incentives to develop better digital imaging techniques. This wave of digital research helped by providing the researcher with less expensive tools. The advanced imaging equipment being used in current research is a by-product of the digital demands of the consumer market.

Images and Learning

Scientific images have been found dating back to 200A.D. (Robin 1992). With this long history of association, it is easy to understand why individuals automatically assume that images enhance scientific learning. Time breeds complacency and acceptance without proof.
There are many questions that can be asked about the relationship between images and science education. If imaging is such an integral part of science, what effect does it have on science education? Do all students benefit equally from using images in the science classroom? How are the available images used in the science classroom and which ways are better? The list of questions that need answers is long. Understanding of the role of images in the science classroom is emerging and there are many questions that still need investigation.

The selection of the research questions came about through a natural progression. As an experienced mathematics educator, the researcher could not imagine giving students a complex graph to analyze unless they understood the basic mechanics involved in creating the graph. Science teachers give student images of complex phenomena and expect them to learn from these images. In mathematics education, the student learns basic graphing skills and techniques before being asked to interpret an existing graph. The question then became if a significant difference was indicated when images were pre-existing or taken by students. A second questioned whether or not the understanding of the techniques used made a significant difference when viewing pre-existing media.

**Limitations of the Study**

The participants had a limited science background with no prior experience working in a science laboratory. Although science education requirements have improved over the last 20 years, it is still treated as minor subject. One day a week was taken from the regular science curriculum to have the science teacher teach these students other mandatory material.

The study was limited by the need to spread the lessons over a 7-week time span. This stretched the time students had to rotate between teachers and curriculum. There was also a 5-day weekend toward the end of the study. Unexpected delays in school construction also added to the limitations.
The amaryllis is an excellent choice of flowers to work with in the classroom but forcing them to bloom from August to October created many problems, starting with locating suitable bulbs, and ending with unpredictable growth. This was the only time available for the study. The researcher was fortunate to have a school whose entire staff did everything in their power to make the study a success. It is recommended that the unit be done during the months of the year when the local stores have fresh amaryllis bulbs available that are intended for forced blooming indoors.

**Implications for Future Research**

The qualitative data collected in this study indicate a student belief that taking science images rather using pre-existing images helps improve understanding. They also indicated that the students spent more time focusing on what was being photographed. At the same time the quantitative data showed no significant increase in test scores when the students created their own images. Increased test scores are important with today’s accountability criteria, and this unit does not reduce them. But it was a knowledge test, not a skills test. Qualitative findings show the treatment students also developed several kinds of inquiry skills that the test instrument did not detect. The national/state reform efforts encourage the development of science inquiry skills and this study shows that human constructivist-based scientific imaging activities can help.

It was not always easy to determine which imaging technique the comments were directed toward. Future research should separate the inquiry into three separate studies. Each study should independent investigation to determine if learning is enhanced by student generated images using either still, time-lapse, or stroboscopic photographic techniques.

Although most of the student have known the researcher for years and have been taught by the researcher when modeling lessons for their teacher, the researcher was still not their
regular teacher. Would the results have been different if the researcher taught the regular science teacher how to use the equipment and then let that teacher present the lessons?

**Conclusion**

When all of the quantitative and qualitative data are viewed together, the advantages of image-based teaching come into focus. The quantitative data indicate no significant difference. This means that the classroom attention devoted to student imaging did no harm to the treatment students’ plant science test scores. However, the qualitative data show that the students in the image-making group, while performing as well as the image-using group on a plant science knowledge test, also experienced growth in inquiry skills, increased understanding of the relationship between technology and science, improved interest in their science course work, and enhanced scientific image interpretation capabilities. It also suggests that the fine color images in biology books are not of appreciable learning value to the students unless the teacher and students make specific pedagogical use of them. What is true for fishing may also be true for biological imaging: “GIVE a person an image; you may interest him/her in nature one day. But, teach a person to MAKE an image; and you will have changed how s/he sees nature for a lifetime.” The act of framing is an act of focusing attention. And isn’t that the first prerequisite for all science learning?
REFERENCES


APPENDIX A

LOUISIANA 7TH GRADE SCIENCES GRADE LEVEL EXPECTATIONS (GLE’S)

Science as Inquiry

The Abilities Necessary to Do Scientific Inquiry
1. Generate testable questions about objects, organisms, and events that can be answered through scientific investigation (SI-M-A1)
2. Identify problems, factors, and questions that must be considered in a scientific investigation (SI-M-A1)
3. Use a variety of sources to answer questions (SI-M-A1)
4. Design, predict outcomes, and conduct experiments to answer guiding questions (SI-M-A2)
5. Identify independent variables, dependent variables, and variables that should be controlled in designing an experiment (SI-M-A2)
6. Select and use appropriate equipment, technology, tools, and metric system units of measurement to make observations (SI-M-A3)
7. Record observations using methods that complement investigations (e.g., journals, tables, charts) (SI-M-A3)
8. Use consistency and precision in data collection, analysis, and reporting (SI-M-A3)
9. Use computers and/or calculators to analyze and interpret quantitative data (SI-M-A3)
10. Identify the difference between description and explanation (SI-M-A4)
11. Construct, use, and interpret appropriate graphical representations to collect, record, and report data (e.g., tables, charts, circle graphs, bar and line graphs, diagrams, scatter plots, symbols) (SI-M-A4)
12. Use data and information gathered to develop an explanation of experimental results (SI-M-A4)
13. Identify patterns in data to explain natural events (SI-M-A4)
14. Develop models to illustrate or explain conclusions reached through investigation (SI-M-A5)
15. Identify and explain the limitations of models used to represent the natural world (SI-M-A5)
16. Use evidence to make inferences and predict trends (SI-M-A5)
17. Recognize that there may be more than one way to interpret a given set of data, which can result in alternative scientific explanations and predictions (SI-M-A6)
18. Identify faulty reasoning and statements that misinterpret or are not supported by the evidence (SI-M-A6)
19. Communicate ideas in a variety of ways (e.g., symbols, illustrations, graphs, charts, spreadsheets, concept maps, oral and written reports, equations) (SI-M-A7)
20. Write clear, step-by-step instructions that others can follow to carry out procedures or conduct investigations (SI-M-A7)
21. Distinguish between observations and inferences (SI-M-A7)
22. Use evidence and observations to explain and communicate the results of investigations (SI-M-A7)
23. Use relevant safety procedures and equipment to conduct scientific investigations (SI-M-A8)
24. Provide appropriate care and utilize safe practices and ethical treatment when animals are involved in scientific field and laboratory research (SI-M-A8)

Understanding Scientific Inquiry
25. Compare and critique scientific investigations (SI-M-B1)
26. Use and describe alternate methods for investigating different types of testable questions (SI-M-B1)
27. Recognize that science uses processes that involve a logical and empirical, but flexible, approach to problem solving (SI-M-B1)
29. Explain how technology can expand the senses and contribute to the increase and/or modification of scientific knowledge (SI-M-B3)
30. Describe why all questions cannot be answered with present technologies (SI-M-B3)
31. Recognize that there is an acceptable range of variation in collected data (SI-M-B3)
32. Explain the use of statistical methods to confirm the significance of data (e.g., mean, median, mode, range) (SI-M-B3)
33. Evaluate models, identify problems in design, and make recommendations for improvement (SI-M-B4)
34. Recognize the importance of communication among scientists about investigations in progress and the work of others (SI-M-B5)
35. Explain how skepticism about accepted scientific explanations (i.e., hypotheses and theories) leads to new understanding (SI-M-B5)
36. Explain why an experiment must be verified through multiple investigations and yield consistent results before the findings are accepted (SI-M-B5)
37. Critique and analyze their own inquiries and the inquiries of others (SI-M-B5)
38. Explain that, through the use of scientific processes and knowledge, people can solve problems, make decisions, and form new ideas (SI-M-B6)
39. Identify areas in which technology has changed human lives (e.g., transportation, communication, geographic information systems, DNA fingerprinting) (SI-M-B7)
40. Evaluate the impact of research on scientific thought, society, and the environment (SI-M-B7)

Physical Science
Properties and Changes of Properties in Matter
1. Identify the elements most often found in living organisms (e.g., C, N, H, O, P, S, Ca, Fe) (PS-M-A9)

Life Science
Structure and Function in Living Systems
2. Compare the basic structures and functions of different types of cells (LS-M-A1)
3. Illustrate and demonstrate osmosis and diffusion in cells (LS-M-A1)
4. Compare functions of plant and animal cell structures (i.e., organelles) (LS-M-A2)
5. Compare complete and incomplete metamorphosis in insects (e.g., butterflies, mealworms, grasshoppers) (LS-M-A3)
6. Compare the life cycles of a variety of organisms, including non-flowering and flowering plants, reptiles, birds, amphibians, and mammals (LS-M-A3)
7. Construct a word equation that illustrates the processes of photosynthesis and respiration (LS-M-A4)
8. Distinguish between aerobic respiration and anaerobic respiration (LS-M-A4)
9. Relate structural features of organs to their functions in major systems (LS-M-A5)
10. Describe the way major organ systems in the human body interact to sustain life (LS-M-A5)
11. Describe the growth and development of humans from infancy to old age (LS-M-A6)
12. Explain how external factors and genetics can influence the quality and length of human life (e.g., nutrition, smoking, drug use, exercise) (LS-M-A6)
13. Identify and describe common communicable and noncommunicable diseases and the methods by which they are transmitted, treated, and prevented (LS-M-A7)
Reproduction and Heredity
14. Differentiate between sexual and asexual reproduction (LS-M-B1)
15. Contrast the processes of mitosis and meiosis in relation to growth, repair, reproduction, and heredity (LS-M-B1)
16. Explain why chromosomes in body cells exist in pairs (LS-M-B2)
17. Explain the relationship of genes to chromosomes and genotypes to phenotypes (LS-M-B2)
18. Recognize genetic errors caused by changes in chromosomes (LS-M-B2)
19. Apply the basic laws of Mendelian genetics to solve simple monohybrid crosses, using a Punnett square (LS-M-B3)
20. Explain the differences among the inheritance of dominant, recessive, and incomplete dominant traits (LS-M-B3)
21. Use a Punnett square to demonstrate how sex-linked traits are inherited (LS-M-B3)
22. Give examples of the importance of selective breeding (e.g., domestic animals, livestock, horticulture) (LS-M-B3)

Populations and Ecosystems
23. Classify organisms based on structural characteristics, using a dichotomous key (LS-M-C1)
24. Analyze food webs to determine energy transfer among organisms (LS-M-C2)
25. Locate and describe the major biomes of the world (LS-M-C3)
26. Describe and compare the levels of organization of living things within an ecosystem (LS-M-C3)
27. Identify the various relationships among plants and animals (e.g., mutualistic, parasitic, producer/consumer) (LS-M-C4)
28. Differentiate between ecosystem components of habitat and niche (LS-M-C4)
29. Predict the impact changes in a species’ population have on an ecosystem (LS-M-C4)

Adaptations of Organisms
30. Differentiate between structural and behavioral adaptations in a variety of organisms (LS-M-D1)
31. Describe and evaluate the impact of introducing nonnative species into an ecosystem (LS-M-D1)
32. Describe changes that can occur in various ecosystems and relate the changes to the ability of an organism to survive (LS-M-D2)
33. Illustrate how variations in individual organisms within a population determine the success of the population (LS-M-D2)
34. Explain how environmental factors impact survival of a population (LS-M-D2)

Science and the Environment
35. Identify resources humans derive from ecosystems (SE-M-A1)
36. Distinguish the essential roles played by biotic and abiotic components in various ecosystems (SE-M-A1)
37. Identify and describe the effects of limiting factors on a given population (SE-M-A2)
38. Evaluate the carrying capacity of an ecosystem (SE-M-A2)
39. Analyze the consequences of human activities on ecosystems (SE-M-A4)
40. Construct or draw food webs for various ecosystems (SE-M-A5)
41. Describe the nitrogen cycle and explain why it is important for the survival of organisms (SE-M-A7)
42. Describe how photosynthesis and respiration relate to the carbon cycle (SE-M-A7)
43. Identify and analyze the environmental impact of humans’ use of technology (e.g., energy production, agriculture, transportation, human habitation) (SE-M-A8)
APPENDIX B

INSTITUTIONAL REVIEW BOARD (IRB) EXEMPTION REQUEST
IRB #:_____________ LSU Proposal #:_____________ Revised: 06/16/2006
LSU INSTITUTIONAL REVIEW BOARD (IRB) for 578-8692 FAX 6792
HUMAN RESEARCH SUBJECT PROTECTION Office:203 B-1 David Boyd Hall
APPLICATION FOR EXEMPTION FROM INSTITUTIONAL OVERSIGHT
Unless they are qualified as meeting the specific criteria for exemption from Institutional Review
Board (IRB) oversight, ALL LSU research/projects
using living humans as subjects, or samples or data obtained from humans, directly or indirectly,
with or without their consent, must be approved or
exempted in advance by the LSU IRB. This Form helps the PI determine if a project may be
exempted, and is used to request an exemption.
Instructions: Complete this form.
Exemption Applicant: If it appears that your study qualifies for exemption send:
(A) Two copies of this completed form,
(B) a brief project description (adequate to evaluate risks to subjects and to explain your
responses to Parts A & B),
(C) copies of all instruments to be used. If this proposal is part of a grant proposal include
a copy of the proposal
and all recruitment material.
(D) the consent form that you will use in the study. A Waiver of Written Informed Consent
is attached and must be completed
only if you do not intend to have a signed consent form.
(E) Certificate of Completion of Human Subjects Protection Training for all personnel
involved in the project ( including students who are
involved with testing or handling data) at
http://cme.cancer.gov/clinicaltrials/learning/humanparticipant-protections.asp. (Unless
already
on file with the IRB.)
to: ONE screening committee member (listed at the end of this form)in the
most closely related department/discipline or to IRB office.
If exemption seems likely, submit it. If not, submit regular IRB application. Help is available
from Dr. Robert Mathews,
578-8692, irb@lsu.edu or any screening committee member.

Principal Investigator ______ Louis J. Schultz Sr. ______ Student Y Y/N
Ph: 985-878-2978 ______ E-mail lschultz@selu.edu ______ Dept/Unit Curriculum & Instruction

If Student, name supervising professor ______ Dr. James Wandersee ______ Ph: 225-578-2348
Mailing Address ______ 54769 Mashon Rd. Independence, LA 70443 ______ Ph: 985-878-2978
Project Title ______ Using Time-Lapse and Stroboscopic Photography To Enhance Student
Understanding of Plant Growth, Structure, and Pollination: An Inquiry-Based Study

Agency expected to fund project ______ Self
Subject pool (e.g. Psychology Students) ______ 7th Grade students
Circle any "vulnerable populations" to be used: (children <18; the mentally impaired, pregnant women, the aged, other). Projects with incarcerated persons cannot be exempted.

I certify my responses are accurate and complete. If the project scope or design is later changed I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted.

PI Signature __________________________ Date __________ (no per signatures)

Screening Committee Action: Exempted ____ Not Exempted ____ Category/Paragraph

Reviewer __________________________ Signature __________________________________ Date

Part A: DETERMINATION OF "RESEARCH" and POTENTIAL FOR RISK

This section determines whether the project meets the Department of Health and Human Services (HSS) definition of research involving human subjects, and if not, whether it nevertheless presents more than "minimal risk" to human subjects that makes IRB review prudent and necessary.

1. Is the project involving human subjects a systematic investigation, including research, development, testing, or evaluation, designed to develop or contribute to generalizable knowledge? (Note some instructional development and service programs will include a "research" component that may fall within HSS’ definition of human subject research).

[ ] YES

[ ] NO

2. Does the project present physical, psychological, social or legal risks to the participants reasonably expected to exceed those risks normally experienced in daily life or in routine diagnostic physical or psychological examination or testing? You must consider the consequences if individual data inadvertently become public.

[ ] YES Stop. This research cannot be exempted--submit application for IRB review.

[ ] NO Continue to see if research can be exempted from IRB oversight

3. Are any of your participants incarcerated?

[ ] YES Stop. This research cannot be exempted--submit application for IRB review.

[ ] NO Continue to see if research can be exempted from IRB oversight.

4. Are you obtaining any health information from a health care provider that contains any of the identifiers listed below?
A. Names
B. Address: street address, city, county, precinct, ZIP code, and their equivalent geocodes. Exception for ZIP codes: The initial three digits of the ZIP Code may be used, if according to current publicly available data from the Bureau of the Census: (1) The geographic unit formed by combining all ZIP codes with the same three initial digits contains more than 20,000 people; and (2) the initial three digits of a ZIP code for all such geographic units containing 20,000 or fewer people is changed to ‘000’. (Note: The 17 currently restricted 3-digit ZIP codes to be replaced with ‘000’ include: 036, 059, 063, 102, 203, 556, 692, 790, 821, 823, 830, 831, 878, 879, 884, 890, and 893.)
C. Dates related to individuals
   i. Birth date
   ii. Admission date
   iii. Discharge date
   iv. Date of death
   v. And all ages over 89 and all elements of dates (including year) indicative of such age. Such ages and elements may be aggregated into a single category of age 90 or older.
D. Telephone numbers;
E. Fax numbers;
F. Electronic mail addresses;
G. Social security numbers;
H. Medical record numbers; (including prescription numbers and clinical trial numbers)
I. Health plan beneficiary numbers;
J. Account numbers;
K. Certificate/license numbers;
L. Vehicle identifiers and serial numbers including license plate numbers;
M. Device identifiers and serial numbers;
N. Web Universal Resource Locators (URLs);
O. Internet Protocol (IP) address numbers;
P. Biometric identifiers, including finger and voice prints;
Q. Full face photographic images and any comparable images; and
R. Any other unique identifying number, characteristic, or code; except a code used for re-identification purposes; and
S. The facility does not have actual knowledge that the information could be used alone or in combination with other information to identify an individual who is the subject of the information.

☐ YES Stop. This research cannot be exempted--submit application for IRB review.

☒ NO Continue to see if research can be exempted from IRB oversight.

Part B: EXEMPTION CRITERIA FOR RESEARCH PROJECTS
Research is exemptable when all research methods are one or more of the following five categories. Check statements that apply to your study:
1. In education setting, research to evaluate normal educational practices.

2. For research not involving vulnerable people [prisoner, fetus, pregnancy, children, or mentally impaired]: observe public behavior (including participatory observation), or do interviews or surveys or educational tests: The research must also comply with one of the following:
   
   a) the participants cannot be identified, directly or statistically;
   
   or that

   b) the responses/observations could not harm participants if made public;

   or that

   c) federal statute(s) completely protect all participants’ confidentiality;

   or that

3. For research not involving vulnerable people [prisoner, fetus, pregnancy, children, or mentally impaired]: observe public behavior (including participatory observation), or do interviews or surveys or educational tests: all respondents are elected, appointed, or candidates for public officials.

4. Uses only existing data, documents, records, or specimens properly obtained. The research must also comply with one of the following:

   a) subjects cannot be identified in the research data directly or statistically, and no -one can trace back from research data to identify a participant;

   or that

   b) the sources are publicly available

5. Research or demonstration service/care programs, e.g. health care delivery. The research must also comply with all of the following:

   a) It is directly conducted or approved by the head of a US Govt. department or agency.

   and that

   b) it concerns only issues under usual administrative control (48 Fed Reg 9268-9), e.g., regulations, eligibility, services, or delivery systems;

   and that

   c) its research/evaluation methods are also exempt from IRB review.

6. For research not involving vulnerable volunteers [see “2 & 3” above], do food research to evaluate quality, taste, or consumer acceptance. The research must also comply with one of the following:

   a) the food has no additives;

   or that

   b) the food is certified safe by the USDA, FDA, or EPA.
NOTE: Copies of your IRB stamped consent form must be used in obtaining consent. Even when exempted, the researcher is required to exercise prudence in protecting the interests of research subjects, obtain informed consent if appropriate, and must conform to the Ethical Principles and Guidelines for the Protection of Human Subjects (Belmont Report), 45 CFR 46, and LSU Guide to Informed Consent; (Available from OSP or http://www.lsu.edu/irb) HUMAN SUBJECTS SCREENING COMMITTEE MEMBERS can assist & review:

COLLEGE OF ARTS AND SCIENCES: MASS COMMUN/SOC WK/AG:  
Dr. Noell * (Psych) 578-4119 Dr. Nelson (Mass C) 578-6686  
Dr. Geiselman * (Psych) 763-2695 Dr. Archambeault(Soc Wk) 8-1374  
Dr. Beggs (Socio) 578-1119 Dr. Keenan* (Hum Ecol) 578-1708  
Dr. Honeycutt(Comm.Stu.) 578-6676 Dr. Belleau (Hum Ecol) 578-1535  
Dr. Dixit (Comm Sc./Dis) 578-3938 Dr. Osborne (Mass C) 578-9296  
Dr. Copeland* (Psych) 578-4117 Dr. Timothy F. Page (Soc Wk) 578-1358

ED/LIBRARIES/INFO SCI BUSINESS  
Dr. Kleiner (Middleton) 578-2217 Dr. McKee (Marketing) 578-8788  
Dr. Landin* (Kinesiol) 578-2916  
Dr. MacGregor (ELRC) 578-2150  
Dr. Gansle (Curric & I) 578-7213  
(* = IRB member)

Institutional Review Board  
203 B-1 David Boyd Hall  
Louisiana State University and A&M College  
Baton Rouge LA 70803

LSU IRB  
REQUEST FOR WAIVER OF SIGNED INFORMED CONSENT  
*** A copy of the script you will use for oral consent should be included with this form.  
This script should contain the necessary elements for written informed consent (see http://appl003.lsu.edu/osp/osp.nsf/$content/LSU%20IRB%20Documents/$File/chklst.txt)  
*** This form may not be used for exemptions involving children.  
FROM: Name: ________________________________  
Department ________________________________  
TO: Robert C. Mathews, Chairman  
Institutional Review Board for Research with Human Subjects  
DATE: ______________________________________  
RE: IRB# __________________  
TITLE: ______________________________________

I am requesting waiver of signed Informed Consent because:
(a) The consent document would create the principal risk of participating in the study.  
Or  
(b) The research presents no more than minimal risk of harm to subjects and involves no procedures for which written consent is normally required
APPENDIX C

ASSENT AND CONSENT LETTERS

Agreement to Participate in Study

I, ________________________________________, agree to participate in a study investigating the difference in understanding between students who use pre-existing images and those who take their own images in the study of plants and plant behavior. I agree to be interviewed as to my understanding of and attitude toward plants. All directions and tasks will be completed to the best of my ability.

Student’s Signature: ___________________________________________ Date: _________________

Students Age: ______

Parent/Guardian’s Signature: ________________________________ Date: _________________
Consent Form

Project Title: Using time-Lapse and Stroboscopic Photography to Enhance Student understanding of Plant Growth, Structure, and Pollination: An Inquiry-Based Study

Site: Pine Junior/Senior High School

Investigator: Louis J. Schultz Sr.
Department of Mathematics
Southeastern Louisiana University

The investigator will be available for questions at 985-634-1800

Purpose of Study: The purpose of the study is to determine if conceptual understanding and knowledge retention increases when a student is actively involved in the taking of scientific images as compared to observing existing images.

Inclusion Criteria: Students who are currently in the seventh-grade and are enrolled in seventh-grade science

Exclusion Criteria: Students who are not currently in the seventh-grade or are not enrolled in seventh-grade science

Description of Study: The students in the both the control and treatment groups will study plant growth, metamorphism, and reproduction using the National Science Education Standards, the Louisiana Science Benchmarks, and The Louisiana GLE’s. While both groups will be engaged in inquiry-based learning, the control group will only use pre-existing images during their investigations. The treatment group will generate their own images using stroboscopic and time-lapse imaging techniques. Both groups will plant and observe amaryllis flowers grow from bulbs to mature flowering plants.

Benefits: The students will benefit from their opportunity to participate in a real-life scientific inquiry which could improve future teaching and learning. They will also be made aware of and be a participant in techniques used by scientists to accurately record events as they occur.

Risks: There are no known risks to the students.

Right to Refuse: Participation is voluntary, and a child will become part of the study only if both child and parent agree to the child's participation. At any time, either the subject may withdraw from the study or the subject's parent may withdraw the subject from the study without penalty or loss of any benefit to which they might otherwise be entitled.
Privacy: The school records of participants in this study may be reviewed by investigators. Results of the study may be published, but no names or identifying information will be included for publication. Subject identity will remain confidential unless disclosure is required by law.

Financial Information: There is no cost for participation in the study, nor is there any compensation to the subjects for participation.

Signatures: The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigator. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Chairman, Institutional Review Board, (225) 578-8692. I will allow my child to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of this consent form.

Parent's Signature                      Date
_________________________________________  ______________________

The parent/guardian has indicated to me that he/she is unable to read. I certify that I have read this consent from the parent/guardian and explained that by completing the signature line above he/she has given permission for the child to participate in the study.

Signature of Reader                      Date
_________________________________________  ______________________
APPENDIX D

MATERIALS

Material List

Amaryllis Bulbs .................................................................72
Full Grown Blooming Daylily Plants .................................12
Full Grown Blooming Mandevilla Plant .............................1
6 inch Flower Pots ............................................................65

Tree Seeds (Large Pkg contains 50-100 seeds)

  Black Ash (Fraxinus Nigra) ............................................ Large
  Box Elder Maple (Acer Nequndo) .................................... Large
  Flowering Ash (Fraxinus Ornus) ..................................... Large
  Green Ash (Fraxinus Pennsylvanicum) .......................... Large
  Norway Maple (Acer Platanoides) ................................. Large
  Vine Maple (Acer Circinatum) ........................................ Large

Miracle-Gro Potting Soil (Quarts) ....................................128

Dark Room ........................................................................... 1
Three Fold Poster Boards ...............................................10
Spiral Notebooks .............................................................50
APPENDIX E

BLACK ROOM

Black Room Frame

Black Room with Felt Cover
APPENDIX F

IMAGING EQUIPMENT

Digital Cameras ................................................................. 12
Casio QV-2000UX ................................................................. 3
Casio QV-2900UX ................................................................. 3
Casio QV-8000SX ................................................................. 1
Sony Mavica ........................................................................... 4
Kodak Easy Share ............................................................... 1
Tri-Pods ................................................................................. 4
Curved Strobe ....................................................................... 1
ProScope™ Digital Scope-on-a-Rope ...................................... 1
Motic DigiScope™ DS 300 Digital Microscope ...................... 1
APPENDIX G

LESSON PLANS

Day 1 -- Lesson 1

Study Introduction

Pretesting

- Content Pretest
- Attitudinal Survey Pre-study

Overview

- Purpose
- Content
- Logistics

Field Notebook

- Observations
- Feelings
- Questions
This lesson will be given to the treatment group only.

Imaging overview

- Equipment they will be using
- Safety first rules
- Individual and small group work

Learning to use the equipment

- Learning stations around the room
- Station 1 (Activity sheet 1) Single shot digital camera images
- Station 2 (Activity sheet 2) Time-Lapse images with digital camera
- Station 3 (Activity sheet 3) DigiScope™
- Station 4 (Activity sheet 4) Digital Scope-On-A-Rope
Imaging
Activity Sheet 1
Basic Camera Operations

Each member of your group will follow the steps below using the camera provided. (Anytime you have a question ask your instructor for help.)

1. Turn the camera on
2. Set the camera to record
3. Press menu, highlight Function (use the plus button to advance the highlight), press the shutter
4. Highlight Size/Quality and press the shutter
5. Set the quality to fine and press the shutter
6. Press menu, highlight normal, press the shutter
7. Set the image distance to close (Flower image appears)
8. Turn the flash off (lightening bolt in circle appears)
9. On the plant provided pick something that you want to photograph
10. Get approximately 2 feet away from the plant and aim your camera at what you want to photograph, use the zoom to get exactly what you want (zoom in or out to get the best picture)
11. When you are looking at what YOU want to capture slowly push the shutter in half way (this will automatically focus your shot)
12. When the image is in focus gently push the shutter until the camera takes the picture
13. Turn the flash on and retake the picture
14. Turn the camera to play and look at both pictures (Share them with your group and discuss the difference when using the flash)
Imaging
Activity Sheet 2
Time-Lapse Images

Your group will complete the steps below using the camera provided. Please make sure that each group member understands the procedure. (Anytime you have a question ask your instructor for help.)

1. Connect the camera to the tripod provided
2. Turn the camera on
3. Set the camera to record
4. Set the flash to on (lightening bolt appears)
5. Set distance to automatic (no symbol)
6. Press menu, highlight interval (use the plus button to advance the highlight), press the shutter
7. With shots selected press the plus or minus button until 3 shots appear, press the shutter
8. With interval selected press the plus or minus button until 01 min appears, press the shutter
9. With start time selected press the plus or minus button until NOW appears, press the shutter
10. Set the camera to take a picture of the classroom and the students (Use the zoom to get the picture you want)
11. When you are looking at what YOU want to capture slowly push the shutter in half way (this will automatically focus your shot)
12. When the image is in focus gently push the shutter until the camera takes the picture
13. The camera will automatically shut off or sleep until it is time to take the next picture. It will then focus itself and take the next picture, you will see the green light come back on and then the flash. This will continue until it takes the number of pictures you told it to take or you stop it by turning the camera on manually.

15. When it has take the three pictures you asked it take you can look at your pictures.

16. Turn the camera on

17. Set it to play

18. Using the plus or minus buttons look at your images. Notice how you can use the pictures to see changes that occurred in the room.

19. List some of the changes you noticed in your field notebook.

20. Set the camera to play, press menu

21. Using the plus button highlight delete, press shutter, us the plus button to highlight all, press shutter, use plus button to select yes, press shutter. (This will permanently delete the images from the camera)
Your group will complete the steps below using the camera provided. Please make sure that each group member understands the procedure. (Anytime you have a question ask your instructor for help.)

1. Turn the computer on.
2. Connect the™ DS 300 to the computer using the USB port.
3. Turn the bottom light on the DigiScope™ on to maximum intensity
4. Double click the Motic Educator Program on the desktop
5. Place the calibration slide on the white slide stage
6. Click on the word capture
7. Place the objective magnification to 20X
8. Click the word calibration
9. Focus Set the magnification slide to match the objective magnification 20X
10. Click on the 2000 circle to match the size of the 2000um calibration dot being used
11. Focus the image then click calibration
12. Go to the image of the dot on the microscope and measure the diameter and area of the image on the screen using the tools provided.
13. Record your findings
14. Using the plant provided each person in the group will select something of interest to put under the microscope
15. Focus your object
16. Click capture to take a picture of the object

17. Measure the length and the area of any part of the object

18. Make a record of what you observed and measured in your notebook.

19. Try different magnification on the scope and look at your image on full screen. (press escape to get back to the normal screen)

20. Remove the slide and turn the DigiScope™ light off

21. Close the Motic Educator program

22. Click on the Safely remove icon (bottom right) and QSI

23. When O.K. to disconnect remove the USB cable
Your group will complete the steps below using the microscope provided. Please make sure that each group member understands the procedure. (Anytime you have a question ask your instructor for help.)

24. Turn the computer on.
26. On the computer desktop click Start, click Program, double click USB SHOT
27. Select Snap Shot by clicking on the Camera icon on the upper right (a camera icon will appear below the three icons on the right side)
28. On the lower left side click on the Folder Selection Icon
29. On the desktop double click the Pine Plant Images folder, double click the folder with your group name. (This will save your images to your folder)

**30. STOP. HAVE YOUR INSTRUCTOR SHOW YOU HOW TO PROPERLY REMOVE AND REPLACE THE LENS ON THE SCOPE BEFORE PROCEEDING.**

31. Using the lowest magnification adjust the scope until you have a clear image on the screen. Using the Capture button on the scope take a picture
32. What appears at the bottom?
33. Change the lens to the highest magnification and take another picture of the same thing
34. Record what you think about both images and what they allow you to see
35. Click on the thumbnail of your first image, it should appear on the screen
36. Click on the Thumbnail/Memo Selector on the lower left

37. Enter a memo about you image (My first image followed by your name), click the selector again.

38. Click on the X in the upper right hand corner (turns off the USB Shot Program)

39. Click on the Safely remove icon (bottom right) and Scope

40. When O.K. to disconnect remove the USB cable
Day 3 -- Lesson 3
Bulbs

Lecture-Discussion

The function of each of following parts of a bulb will be discussed.

- Tunic
- Fleshy scales
- Basal plate
- Roots
- Shoot
- Lateral buds

The control groups will be given amaryllis bulbs to plant. They will also be given images with which to make observations and will record their observations in their field notes. The images will be of both a whole amaryllis bulb and an amaryllis bulb that has been cut in half.

The treatment groups will be given amaryllis bulbs to plant but will be required to take pictures of the bulb parts discussed. After they have taken their images and recorded their observations they will plant the bulbs.

Both groups will plant new bulbs each week for five consecutive weeks. This will allow for the amaryllis to be visible to the students at various growth stages throughout the study.
Day 4 -- Lesson 4C
Metamorphosis -- Scape – Spathe

DIRECTIONS: You will work together in your group to answer each of the following questions. We will work one question at a time, discuss the answers as a class, and then go on to the next question. Your group does not have to agree on a single answer. Discuss the question and then each person is to write their own answer. (You only have a few minutes to write your answer so work efficiently.)

1. What is metamorphosis? Does it apply to plants?

Examine the images provided and then complete the following:
2. Completely describe what you see growing up from the center of the bulb.

What do you think the functions of these parts are?
DIRECTIONS: You will work together in your group to answer each of the following questions. We will work one question at a time, discuss the answers as a class, and then go on to the next question. Your group does not have to agree on a single answer. Discuss the question and then each person is to write their own answer. (You only have a few minutes to write your answer so work efficiently.)

3. What is metamorphosis? Does it apply to plants?

Take pictures of plant parts growing up from the center of the bulb, then answer the following:

4. Completely describe what you see growing up from the center of the bulb.

5. What do you think the functions of these parts are?

Set up time-lapse imaging of a growing amaryllis flower
1. Your science assignment requires you to take a picture of an autotroph for your notebook. If you had a digital camera, what could you take a picture of to complete the assignment? (Circle all choices that would work)
   a. dog  b. grass  c. horse  d. cow  e. certain plankton
   f. rabbit  g. goat  h. wheat  i. bean plant  j. deer

2. What do the correct answers to number 1 all have in common?

3. Construct what you think is a good definition of an autotroph.

4. Why do you think autotrophs are important?

5. Would you expect the total biomass of autotrophs to be large or small? Justify your answer.

6. What do you think would be limiting factors to the autotroph population?
Day 5 -- Lesson 6
Photosynthesis

Lecture and Discussion

How do autotrophs synthesis organic substances from organic molecules using light energy?

• What is an organic substance?
• What is the process called?
• What is required for photosynthesis to take place?
• Where does it take place?
• What is the equation for this process?
• What does this equation mean?
Day 6 -- Lesson 7
Photosynthesis

Photosynthesis Continued

Review of lesson 6: Discussion

- What is photosynthesis?
- Where does it take place?
- What does it require?
- What is the equation for photosynthesis?

Expansion

- What parts of plant are involved in the process and what is their role?

The control group will be given pictures of the amaryllis and asked to identify those parts of the plant that are involved in the photosynthesis process and to describe what the function of each part is in the process.

The treatment group will be directed to take images of the parts of the plant that play a role in the photosynthesis process and describe what the function of each part is in the process.
Day 7 -- Lesson 8C
Asexual Reproduction of Plants

DIRECTIONS: You will work together in your group to answer each of the following questions. We will work one question at a time, discuss the answers as a class, and then go on to the next question. Your group does not have to agree on a single answer. Discuss the question and then each person is to write their own answer. (You only have a few minutes to write your answer so work efficiently.)

1. Most of us have seen plants reproduce but what is called asexual reproduction. This is when a new plant is produced without the formation of an embryo. Discuss times that you saw someone start a new plant started but without using seeds. Write down methods you have seen.

2. There are two means of asexual reproduction that can be used to reproduce amaryllis: (1) offshoot and (2) cuttage (twin scaling). Look at the images provided and record your observations on each of these methods.
DIRECTIONS: You will work together in your group to answer each of the following questions. We will work one question at a time, discuss the answers as a class, and then go on to the next question. Your group does not have to agree on a single answer. Discuss the question and then each person is to write their own answer. (You only have a few minutes to write your answer so work efficiently.)

2. Most of us have seen plants reproduce but what is called asexual reproduction. This is when a new plant is produced without the formation of an embryo. Discuss times that you saw someone start a new plant but without using seeds. Write down methods you have seen.

There are two means of asexual reproduction that can be used to reproduce amaryllis: (1) offshoot and (2) cuttage (twin scaling). Using the amaryllis provided photograph each type of asexual reproduction and record your observations.
Day 8 – Lesson 9  
Sexual Reproduction

DIRECTIONS: You will work together in your group to answer each of the following questions. We will start by answering questions 1 and 2 this time, discuss both answers as a class, and then go on to the next question. Your group does not have to agree on a single answer. Discuss the question and then each person is to write their own answer. (You only have a few minutes to write your answer so work efficiently.)

1. What must happen for pollination to take place?

2. What must happen for fertilization to take place?

3. How do you think a plant is pollinated?

4. Name five different pollinators?

Discussion: From pollination to Fertilization

- What are the male parts of the flower?
- What are the female parts of the flower?
Lecture and Discussion:

What is the function of the:

- Stamen
- Filament
- Anther
- Pollen
- Pistil
- Style
- Stigma
- Tepal
- Ovary Wall
- Ovule

The control groups will use their own plants and point to the above parts as the researcher moves from group to group.

The treatment groups will use their own plants to photograph each of the above parts.
Day 10 Lesson 11
Pollination

Lecture and Discussion

Pollinators
- What is a pollinator?
- Mutual benefits to plant and pollinator

Pollination
- Self pollination
- Cross pollination
  - Entomophily
  - Zoophily
  - Abiotic
    - Anemophily
    - Hydrophy

Cross Pollinating Amaryllis

- Students will view images of pollinators visiting flowers
- The students will play the role of pollinator by using Q-Tips to transfer pollen from one flower and using it to pollinate their own flower.
- The treatment group will take images of the process
Day 11 – Lesson 12C
Seed dispersion

Lecture and Discussion

• Importance of dispersion

• Methods of dispersion

Images

• Still images of dispersion

• Movie clips of dispersion
Day 11 – Lesson 12T
Seed Dispersion

The treatment group will be instructed in the taking of stroboscopic images utilizing a black room. Each group will be given the opportunity to photograph the natural aeronautical mechanisms using by some plants for seed dispersion.

When not engaged in the taking of stroboscopic images the groups will rotate to stations where they will view images of various techniques used by plants for seed dispersion.
Day 12 – Lesson 13C
Recap of Plant Study

Discussion

• Each group will be given 15 minutes to review their field notebooks and images used during the study for understanding.

• With the aid of images projected on a screen, the researcher will review the content covered in this study.

• Student will be given the opportunity to ask questions and clarify their understanding.
Day 12 – Lesson 13T
Recap of Study

Finalizing Images

- Make an AVI movie from the time-lapse images taken. Record their observations.
- Compile a set of images that show the chronology and content of their plant study.
- Write a brief statement in their field notebook expressing how they feel about taking the images during these lessons.
Study Conclusion

Posttesting

• Content Posttest

• Attitudinal Survey Post-study

Appreciation

• Thanking the students, teacher, and school for their cooperation.

• Christmas Amaryllis – as show of appreciation and a sincere hope that the students will grow in their appreciation of plant and flowers each student will receive an amaryllis of their own to grow over the Christmas holidays.

• Some of the flowers used in the study will be given to the school for their flower beds.
APPENDIX H

PRETEST AND POSTTEST

PreTest Student Number ______________

Please answer each of the following questions by writing the letter of the correct answer in the space provided.

_____ 1. The basal plate
   A. is a circular ridge at the base of a flower
   B. is a source of nutrition for the growing plant
   C. is where the roots attach to the bulb
   D. is where the insect get the nectar from the flower

_____ 2. During transpiration water is lost through the
   A. vascular tubes
   B. scape
   C. spathe
   D. stomata

_____ 3. Photosynthesis
   A. uses water
   B. uses carbon monoxide
   C. uses carbohydrates
   D. all of the above

_____ 4. The flower is protected by
   A. scapes
   B. bracts
   C. stigma
   D. tepal

_____ 5. Sepals and tepals are part of the
   A. roots
   B. flowers
   C. leaves
   D. bulbs

_____ 6. Plants
   A. never move
   B. move only when something else moves them
   C. create their own motion
   D. none of the above
7. Flowering plants can reproduce by
   A. cuttage
   B. seeds
   C. offshoots
   D. all of the above

Please answer each of the following questions by writing the letter of the correct answer in the space provided.

8. Flowers are colorful to
   A. enhance gardens
   B. sell easier
   C. attract pollinators
   D. reflect excess sunlight

9. The anther is located at the end of the
   A. style
   B. stigma
   C. filament
   D. spathe

10. Plant food is
    A. made by the plant
    B. absorbed through the roots
    C. absorbed through the leaves
    D. both B and C

For each of the following questions select the statement that is true and write the letter of the correct statement in the space provided.

11. A. Metamorphosis occurs when a plant grows.
    B. Metamorphosis occurs only when a caterpillar changes into a butterfly.

12. A. \( C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{light energy}} 6CO_2 + 6H_2O \)
    B. \( 6CO_2 + 6H_2O + \text{light energy} \xrightarrow{\text{}} C_6H_{12}O_6 + 6O_2 \)

13. A. The stigma is at the end of the style
    B. The stigma is at the end of the filament

14. A. Nutrients enter the plant through the leaves.
    B. Nutrients enter the plant through the roots.

15. A. The top side of a leaf has a wax like coating
    B. The bottom side of a leaf has a wax like coating.
16. A. Plants use natural aerodynamic designs to increase seed distribution.
   B. Plants use natural aerodynamic designs to increase landing zone for pollinators.

17. A. Pollination is another name for fertilization.
   B. Pollen tubes grow from the stigma to the ovary.

Use each pictures to answer the question associated with it. Write the correct answer in the space provided.

18. Where did the powdery substance on the leaves originate?
   A. style
   B. stigma
   C. anther
   D. scape

19. What service is the bee providing to the plant?
   A. Relieving it of an over abundance of nectar.
   B. Transporting pollen between plants
   C. Eating harmful mites
   D. Providing nutrients to the young seeds

20. What is the purpose of this plant part?
   A. Produce pollen
   B. Receive pollen
   C. Produce seeds
   D. Protect seeds
Write the letter of the label that matches each of the following functions in the space provided.

21. _____ Source of nutrition for early growth
22. _____ Absorbs nutrients for photosynthesis
23. _____ Where carbohydrates are produced
24. _____ Where the embryo develops
25. _____ Provides nutrient transport through vascular tubes.
26. _____ Collects pollen
27. _____ Encompasses both the male and female reproductive organs
28. _____ Transferred by insects
Please answer each of the following questions by writing the letter of the correct answer in the space provided.

_____ 1. Plant food is
   E. made by the plant
   F. absorbed through the roots
   G. absorbed through the leaves
   H. both B and C

_____ 2. Flowering plants can reproduce by
   E. cuttage
   F. seeds
   G. offshoots
   H. all of the above

_____ 3. Photosynthesis
   E. uses water
   F. uses carbon monoxide
   G. uses carbohydrates
   H. all of the above

_____ 4. Flowers are colorful to
   E. enhance gardens
   F. sell easier
   G. attract pollinators
   H. reflect excess sunlight

_____ 5. Sepals and tepals are part of the
   E. roots
   F. flowers
   G. leaves
   H. bulbs

_____ 6. The basal plate
   E. is a circular ridge at the base of a flower
   F. is a source of nutrition for the growing plant
   G. is where the roots attach to the bulb
   H. is where the insect get the nectar from the flower

_____ 7. Plants
   E. never move
   F. move only when something else moves them
   G. create their own motion
   H. none of the above
PostTest

Student Number

Please answer each of the following questions by writing the letter of the correct answer in the space provided.

8. During transpiration water is lost through the
   E. vascular tubes
   F. scape
   G. spathe
   D. stomata

9. The flower is protected by
   E. scapes
   F. bracts
   G. stigma
   H. tepal

10. The anther is located at the end of the
    E. style
    F. stigma
    G. filament
    H. spathe

For each of the following questions select the statement that is true and write the letter of the correct statement in the space provided.

11. A. Plants use natural aerodynamic designs to increase seed distribution.
    B. Plants use natural aerodynamic designs to increase landing zone for pollinators.

12. A. \(6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2\)
    B. \(C_6H_{12}O_6 + 6O_2 + \text{light energy} \rightarrow 6CO_2 + 6H_2O\)

13. A. Nutrients enter the plant through the roots.
    B. Nutrients enter the plant through the leaves

14. A. Metamorphosis occurs when a plant grows.
    C. Metamorphosis occurs only when a caterpillar changes into a butterfly.

15. A. Pollination is another name for fertilization.
    B. Pollen tubes grow from the stigma to the ovary.

16. A. The top side of a leaf has a wax like coating
    B. The bottom side of a leaf has a wax like coating.

17. A. The stigma is at the end of the filament
    B. The stigma is at the end of the style
Use each pictures to answer the question associated with it. Write the correct answer in the space provided.

18. What service is the bee providing to the plant?
   E. Relieving it of an over abundance of nectar.
   F. Providing nutrients to the young seeds
   G. Transporting pollen between plants
   H. Eating harmful mites

19. Where did the powdery substance on the leaves originate?
   E. stigma
   F. scape
   G. style
   H. anther

20. What is the purpose of this plant part?
   E. Produce seeds
   F. Protect seeds
   G. Produce pollen
   H. Receive pollen
Write the letter of the label that matches each of the following functions in the space provided.

21. _____ Encompasses both the male and female reproductive organs
22. _____ Provides nutrient transport through vascular tubes.
23. _____ Where carbohydrates are produced
24. _____ Carried by insects
25. _____ Source of nutrition for early growth
26. _____ Collects pollen
27. _____ Where the embryo develops
28. _____ Absorbs nutrients for photosynthesis
APPENDIX I

ATTITUDINAL SURVEY

Botany Attitudinal Survey

Before we begin the study of plants, you are going to take a brief survey on your feeling toward botany (the study of plants). You are asked to rate each statement on the degree to which you agree. For each, you may (A) strongly agree, (B) agree, (C) be undecided, (D) disagree, or (E) strongly disagree.

After you have made your choice, completely fill in the appropriate answer on the Scantron sheet provided.

<table>
<thead>
<tr>
<th>A</th>
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<th>C</th>
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<tr>
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<td></td>
<td></td>
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<td>Agree</td>
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</table>

1. Botany is very interesting to me.
2. I don’t like botany, and it scares me to have to take it.
3. I am always under a terrible strain in botany class.
4. Botany is fascinating to me.
5. Botany makes me feel secure, and at the same time it is stimulating.
6. Botany makes me feel uncomfortable, restless, irritable, and impatient.
7. In general, I have a good feeling toward botany.
8. When I hear the word botany, I have a feeling of dislike.
9. I approach botany with a feeling of hesitation.
10. I really like botany.
11. I have always enjoyed studying botany in school.
12. It makes me nervous to even think about doing a botany experiment.
13. I feel at ease in botany and like it very much.
14. I feel a definite positive reaction to botany.
Below are some scales on which I would like you to rate your feelings toward botany. On each scale you can rate your feelings toward botany as an A, B, C, D, or E. *There are no correct answers.* Please rate your feeling as best you can.

After you have made your choice, completely fill in the appropriate answer on the Scantron sheet provided.

**BOTANY IS:**

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<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
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Field Notes

Each of you will be given a field notebook. A scientist keeps good records of all of his or her activities, observations, data collections, and thoughts. Each day when you are working on your plant inquiry, you are being asked to keep field notes.

What should be in field notes? (Here are some ideas)

- Time and date
- What activity you are doing
- Who you are doing it with
- What do you sense (Observations)
  - See
  - Hear
  - Smell
  - Feel
- What are your thoughts
  - What if….  
  - If I could…..
  - I wonder why…..
  - How I feel about doing this
- Did what I learned today change the way I think
- Sketches

Field notes should be brief yet clear. They will help you more accurately recall your experiences at a later date.

These field notes will be collected and used as a source of data for this project. They will be returned to the participants when the study is completed. The data collected will be compiled as a group with no data being associated to individual participants.


APPENDIX K

CONTROL GROUP IMAGES

Amaryllis Bulb Tunic

Photograph by Daniel Conti 12/29/04
Amaryllis Roots and Basal Plate
Amaryllis Bulb with Offshoot

Photograph by Daniel Conti 12/29/06
Amaryllis Bulb Cutaway

Photograph by Daniel Conti 12/29/04
Amaryllis Scape or Stem

Photograph by Daniel Conti 12/29/04
Amaryllis Scape and Spathe

Photograph by Daniel Conti 12/29/04
Amaryllis with Open Spathe

Photograph by Daniel Conti 12/29/04
Amaryllis Flower Tepals and Sepals

Photograph by Daniel Conti 12/29/04
Amaryllis Stamen with Filament, Anther, and Pollen

Photograph by Daniel Conti 12/29/04
Amaryllis Stigma and Style

Photograph by Daniel Conti 12/29/04
Amaryllis Whole-Plant

Photograph by Daniel Conti 12/29/04
APPENDIX L

PARTICIPANT INTERVIEW

Participant Interview

Thank you for talking with me about the study of plants you just completed. I am going to ask you several questions about what you liked and didn’t like and would appreciate your being as honest and complete as possible. I will not be recording who you are, just your answers. Do you have any questions?

1. What was your opinion of the lessons? Please elaborated
   Probes:
   - What part did you play in the activities?
   - What was something new you learned from these lessons?
   - Was there anything exciting about these lessons?
   - Was there anything that you didn’t like about the lessons?

2. What did you think about the images in these lessons and how they affected your learning?
   Probes:
   - What part did the images play in the lessons?
   - Did the images help your understanding of plants?

3. Why do scientists use time-lapse and high speed photography in their research?
   Probes:
   - What is the benefit of time-lapse photography?
   - What is the benefit of high speed photography?
   - How does a stroboscopic help us with photography?
APPENDIX M

PARTICIPANT DATA

Control Group Data

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APPENDIX N

SCAPE-FLOWER GROWTH WITH LIMITED LEAF GROWTH
APPENDIX O

SAMPLE TREATMENT GROUP IMAGES
APPENDIX P

POSTERS

Control Group Poster Number 1

Control Group Poster Number 2
Control Group Poster Number 3

Control Group Poster Number 4
Treatment Group Poster Number 2

Treatment Group Poster Number 3
Treatment Group Poster Number 4

Treatment Group Poster Number 5
APPENDIX Q

QUALITATIVE CODES, DEFINITIONS, AND EXAMPLES

Qualitative Coding Guide

Code: Increased Knowledge
Definition: Any statement that refers to the participant gaining new knowledge.
Examples: “Today I learned a lot and it was fun.”
“I did not realize how many different parts and features a plant has.”

Code: Fun
Definition: Any statement the references the participant having fun while learning.
Examples: “We did a lot of cool thing. Botany is fun.”
“Today was fun. We learned about bulbs and what a plant was made of.”

Code: New Experience:
Definition: Any statement that indicates the participants was engaged in an activity that he or she had never experienced
Examples: “I planted a bulb today. This is my first one. I can’t wait for it to grow.”
“I touched the inside of the bulb, It was sticky.”
“I learn things that I didn’t even know existed.”

Code: Question Generator
Definition: Any statement that asks a question that would require further investigation not just the re-teaching of what had been already covered.
Examples: “What if there were two bulbs together? Would anything change? If so what would change?” (Referenced to the planting of bulbs)
“If I could I would have cut off the basal plant and looked inside.”

Code: Boring
Definition: Any direct statement of being bored

Examples: “Every time I think or hear about plant’s it’s like boring.”

“Botany can be fun. It can be boring.”

Code: Plant Hater

Definition: Any statement that refers to the participants dislike of plants or botany.

Examples: “Botany is not my favorite, it’s not real interesting. I’m not real good at it. All we do is talk about plants.”

“I really liked taking the pictures in this class. I don’t like plants though. Every time I think or hear about plants it’s like boring. I did learn a lot of things I didn’t know about plants, but I still don’t like talking about them.”

Code: Images Helped:

Definition: Any statement that refers to the images improving the participants learning.

Examples: “I liked taking the pictures. It really helped me understand the parts of the flower better.”

“When we were taking pictures of the plants that I think helped me identify the parts easier, because we were able to study them, watch them grow, and take pictures of exactly how they look.”

“Taking pictures was fun and much easier and exciting then looking at a flower piece of paper.”

Code: Group Lover

Definition: Any statement that says the participant thinks small group activities are beneficial.

Examples: “Working together in groups has helped me get along with other people.”

“I like working in the groups. To me it is every one is doing the same work at the same time.”
Code: Hands-On

Definition: Any statement that makes reference to enjoying hands-on activities

Examples: “I liked the hands-on activities. They make it more fun and interesting.”

“I hope we keep doing hands-on. I learn more this way.”
Pollination Concept Map

Section 2

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sexual reproduction

angiosperms

that produce

flowers

that contain

sepals

that protect and support the

petals

enclosing the

sex organs

gymnosperms
**APPENDIX S**

**GOWIN VEE**

**Research Questions**

Will time-lapse and stroboscopic photography enhance student understanding of a plant’s interactive structure?

Will the understanding of photographic techniques enhance student’s conceptual understanding of scientific information given in image format?

Will the process of taking an image enhance student learning?

Will time-lapse and stroboscopic photograpgh enhance student understanding of plant reproduction?

**Conceptual**

**World Views**

- The world is understandable
- Scientific ideas are subject to change
- Plants are static
- Insects are of little value
- Flowering plants are important only for aesthetic purposes

**Philosophy**

- Mathematics and science should be a hands-on experiences
- Knowledge is constructed by the individual
- Images can enhance learning
- New learning experiences should be based on prior knowledge

**Theories**

- Cognitive Theory
- Human Constructivist Theory
- Dual Coding Theory
- Learning Theory
- Assimilation Theory

**Methodological**

**Value Claims**

- Conceptual understanding and knowledge retention increases when images are produced as part of the learning process
- Increase learning conducive environment
- Creates desire to learn

**Knowledge Claims**

- Imaging increases conceptual understanding
- Imaging increases retention
- Technical knowledge of imaging techniques increases knowledge from

**Transformations**

- Participant data summary table
- Bivariate Plots
- Two-variable linear model
- Analysis of covariance
- Qualitative data coding and comparison

**Records**

- Pre & post content tests results
- Pre & post attitude survey results
- Student field notes
- Student generated still, time-lapse, and stroboscopic images
- Classroom teacher field notes
- Researcher field notes
- Interview responses

**Concepts**

- Reproduction
- Pollination
- Pollinators
- Fertilization
- Mutualism
- Species extinction
- Metamorphosis

**Events/Objects**

- Pre-study standardized science test scores
- Pre- and posttest of student content knowledge
- Pre-Post student attitudinal surveys
- Daily participant feedback
- Growing and observing amaryllis
- Students capturing images
- Structured student interviews
- Classroom teacher observations
- Researcher observations

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VITA

Louis Schultz received a bachelor of science degree (1970) in mechanical and aerospace engineering from Oklahoma State University, a bachelor of science degree (1973) in mathematics education and a master of education degree (1976) in special education from Southeastern Louisiana University, and an educational specialist certification (1999) in curriculum and instruction from Louisiana State University. He has served as a public and private school teacher, principal, chief school system administrator, and director of special education.

Mr. Schultz is currently site-coordinator for the professional development project: Advancing Mathematics Online and Onsite and the university coordinator for the Jefferson Parish Math and Science Partnership grant through the Louisiana State Department of Education. He has been the site-coordinator and/or director of 13 professional development projects in mathematics, science, and technology over the last 10 years in Arkansas, Louisiana, and Mississippi. Mr. Schultz has also served as a committee member and consultant for the Louisiana Department of Education. These included teacher retention, mathematics curriculum development, developing grade level expectations, and comprehensive curriculum. He has also served on the selection committee for the Louisiana Mathematics and Science and Technology project (LaMaST) as well as an instructor for the grantees.

In addition, Mr. Schultz has presented mathematics, science, and technology workshops at the local, state, and regional levels. He has served as a national consultant on the use of graphing calculators and digital cameras to enhance learning. He also co-chaired the 16th International Conference of Teachers Teaching with Technology.

Mr. Schultz is currently a member of the National Council of Teachers of Mathematics, the Louisiana Association of Teachers of Mathematics, the Louisiana Science Teachers Association, The National Education Association, and the Center for Innovative Learning and Technology.