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A New Approach to Using Photographs and Classroom Response Systems in Middle School Astronomy Classes

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A NEW APPROACH TO USING PHOTOGRAPHS AND CLASSROOM RESPONSE SYSTEMS IN MIDDLE SCHOOL ASTRONOMY CLASSES

A Dissertation Presented

by

HYUN JU LEE

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DEDICATION

To my grandfather JeongSuk Kang

who gave me endless love like the stars in the universe.

ACKNOWLEDGMENTS

I am sincerely and heartily grateful to those who made this dissertation possible. I would not have been at this stage of my dissertation without the help and support of them. First of all, I would like to thank my supervisor Prof. Allan Feldman for his guidance, support, and encouragement throughout the whole doctoral program. Furthermore, I would like to thank Prof. John Clement for his insightful comments and encouragement, and Prof. Stephen Schneider for his kind support and comments in astronomy education. I was lucky that I met the three scholars and had opportunities of working with them.

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ABSTRACT

A NEW APPROACH TO USING PHOTOGRAPHS AND CLASSROOM RESPONSE SYSTEMS IN MIDDLE SCHOOL ASTRONOMY CLASSES

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This study reports middle school astronomy classes that implemented photographs and classroom response systems (CRSs) in a discussion-oriented pedagogy with a curriculum unit for the topics of *day-night* and *cause of seasons*. In the new pedagogy, a teacher presented conceptual questions with photographs, her 6th grade students responded using the CRSs, and the teacher facilitated classroom discussion based on the student responses. I collected various data: classroom observation with field-note taking and videotaping, student pre- and post-conception tests, student attitude survey and classroom short surveys, and teacher interviews. Classroom video recordings and teacher interviews were transcribed verbatim and analyzed with the *grounded theory approach*. This approach was used to analyze the open responses of the student attitude survey as well. Pre- and post- conception tests consisted of open-ended questions and they were scored based upon rubrics. Numerical data were analyzed with descriptive statistics and simple t-tests. In this study, I answered three research questions: 1) student-teacher discourses and interaction patterns while learning and teaching with the photographs and CRSs in the new pedagogy; 2) 6th grade students' misconceptions about the concepts of day-night and cause of seasons, and their knowledge gains after they had the intervention; and 3) the students' and the teacher's attitude toward the new curriculum and the new pedagogy. Finally, I discuss the student-teacher interaction model and three important teacher-questionings in this pedagogy; levels of misconceptions; and the pedagogical roles of the photographs and CRSs.

Keywords: *astronomy, photographs, classroom response systems, discourse, classroom discussion*

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CHAPTER 1

INTRODUCTION

As a person who majored in optical astronomy, I have been always curious about how students can learn astronomy as the way astronomers do. Many astronomical phenomena can be observed only in parts on earth and have to be reasonably inferred with the pieces of information to understand the macroscopic phenomena. The source of the information is primarily light. Astronomers collect the information as certain types of images. They analyze the data on images, build scientific models, and simulate computer programs from which they draw scientific conclusions.

It has been reported that students often have various misconceptions about *day-night* and *cause of seasons* and that science teachers often have difficulties to teach the concepts. Ironically, these concepts are very closely related to our daily lives. We experience day and night every day and different seasons every year on most parts of the earth. In addition, these are the most basic concepts in the K-12 astronomy curriculum because they deal with the fundamental concepts of the movement of the earth. They should be familiar concepts. Then, why do so many children have difficulty in understanding them? Are the natures of the concepts themselves really that difficult to understand?

I believe the reason why children often fail to describe these concepts is because they have been more focused on learning the scientific *fact*s without having deep insights about how the facts could relate to what they see in a real world. Therefore, they fail to describe the connection between what they observe in their daily experiences on earth and what they learn in science classes. As a result, their knowledge often exists as superficial and is not deeply embedded in them. So, here I would like to find a way that students focus on observing phenomena on earth and build connections between the observation and scientific concepts.

The Problem

Modern technology has brought us the convenience of using various types of visuals. Now, people watch TV shows and movies at any place with a handy device. People experience virtual reality in the Internet space. People talk with friends and families while watching their faces through visual phones at a distance. Simulation programs and visual software for class are now abundant. However, photographs are still one of the most common visual representations that remain in our daily lives. While we are walking in the street, we easily see advertisements in the form of photographs. Digital cameras become essentials for many people in their lives and bloggers decorate their blogs with photographs every day from all over the world. We see many photographs in magazines, journals and textbooks. Photographs capture a moment of our lives and this can have a strong voice (e.g., Wang & Burris, 1997).

Photographs are not only used in our daily lives, but also in many science laboratories. Biologists take pictures of cell microstructures and chemists take pictures of molecules. Astronomers take pictures of Mars and receive lights from a distant galaxy and save them as a form of photographs. Those scientific photographs are playing an aesthetic role of science for public. However, those have more meaning than that for scientists. Those photographs are one of the data that scientists actually *use* for their scientific research. They carefully observe the photographs, analyze their information, find patterns of the data, answer for questions, and finally draw a scientific conclusion.

There have been many studies about the use of visual representations in science education, such as diagrams (e.g., Ainsworth & Loizou, 2003; Newberry, 2002), graphs (e.g., Bowen & Roth, 2005; Tufte, 1983), and multimedia (e.g., Mayer, 1997; Morena & Mayer, 1999). Interestingly, however, there have been very little studies about photographs in science education except few recent works by Roth and his colleagues (Pozzer & Roth, 2003; Pozzer-Ardenghi & Roth, 2004; Roth, Bowen, & McGinn, 1999). Their studies are initiative works. The pedagogical role of using photographs in science classes are still in need of investigation. Photographs are one of the major visual representations that students see in their classes in their textbooks and that they meet in their daily lives. Hereby, this study started from the reflection: Is there any way that we can employ this common visual representation in science classes?

In this study, I suggest a curriculum unit that employs photographs in a classroom discussion for middle school astronomy classes. In the next section, I describe the background of the study.

Background of the Study

This study is based on two research projects: one is *Thinking Journey (TJ) instruction* that has been performed in Israel and the other one is *Technology-Enhanced Formative Assessment (TEFA)* pedagogy at University of Massachusetts Amherst in USA.

Thinking Journey

(Schur, Skuy, Zietsman, & Fridjhon, 2002; Shapiro, 2007; Schur, Pensso & Schwarz, 2007)

Thinking Journey (TJ) is discussion-based instruction in the context of an imaginary journey (Schur, Skuy, Zietsman, & Fridjhon, 2002). TJ approach introduces a context of multiple perspectives by providing students with pictures (or any type of visual materials), and this plays a central cognitive tool of TJ teaching. Students are guided to recognize the variation of perspectives and their relationship with various environments in the course of journey. TJ instruction focuses on combining *Mediated Learning Experience* (MLE, Feuerstein, Rand, Hoffman, & Miller, 1980) and the constructivist approach (Driver & Oldham, 1986). TJ instruction encourages the interaction between students and a teacher, and the teacher listens and guides students, suggesting how and what to observe in the considered representation of a phenomenon. In the TJ method, teachers play a role of collaborators and mediators for students in making scientific sense of the environment and of facilitators of their students' needs for information and discussion.

The TJ instruction is now accepted as a national curriculum for several science topics in Israel. The TJ instruction was originally developed for the concept of the day/night cycle, comprising a series of learning activities (the following detailed description about TJ day/night cycle activity is from Schur & Galili, not published article):

1) The first perspective: The moon environment

Put yourself on the moon in the place where the astronaut stands (the place of the flag). Describe your immediate environment. Write down questions that you have.

2) The second perspective: The movement of the moon

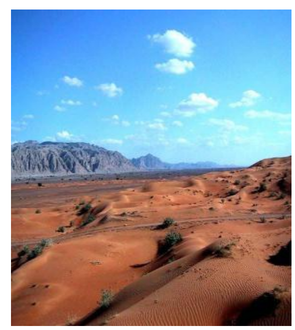
You are standing on the moon while it revolves around the earth. Describe the way you view the earth, the sky and ground of the moon during the revolution of the moon around the earth. Describe the day-night cycle on the earth and on the moon.

3) The third perspective: Day-night cycle on the moon

You are standing together with the astronaut. Is it night or day at the place you are standing? Why do you think so?

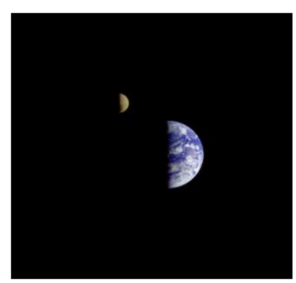
Time passes. Will it be night or day in the place where you are standing in two hours? (6 hours, 24 hours, 15 days, 27 days).

4) The fourth perspective: Earth's environment



Now imagine yourself returned home, to Israel, standing outside and watching the sky. Describe your experience now and address the way the moon, the sun, the stars, the sky appear to you. Describe the day-night cycle now.

5) The fifth perspective: observation from a spaceship



Now you are in a spaceship on the way to Mars. You are watching the earth and the moon from the window. Describe what you see. Relate your description to the day-night cycle of the moon and to the day-night cycle of the earth.

As can be seen in this instruction, TJ focuses on helping students to develop different perspectives by providing them with different environment and allowing them to observe it. As such an environment, TJ uses pictures (mostly photographs). TJ suggests that students can break their egocentric view through this series of activities (Shapiro, 2007).

Technology-Enhanced Formative Assessment

Technology-Enhanced Formative Assessment (TEFA) pedagogy has been developed during the past 15 years by the physics education research group of the Scientific Reasoning Research Institute (SRRI) at the University of Massachusetts Amherst. TEFA pedagogy has main four principles (Beatty & Gerace, 2009):

1) Motivate and focus student learning with *question-driven instruction:*

TEFA pedagogy provides students with the context that they encounter with conceptual questions. Those questions are often challenging to students and give them motivation and context of learning. Beatty and Gerace (2009) noted that "questions are used to set up fertile learning situations and to catalyze learning, not just to assess previous instruction or gather data to inform future instruction. (p.154)" In TEFA pedagogy, teachers present multiple-choice questions to class, and students are engaged in class discussion about the questions. Teachers guide students to think about the question and discuss it with their classmates. Teachers do not tell students the correct answer right away, but they keep it as an open question so students can bring their various ideas to the discussion. Therefore, in TEFA pedagogy, questions play a role as initiators of classroom discussion.

2) Develop student understanding and scientific fluency with *dialogical discourse:*

TEFA pedagogy emphasizes student participation in small-group and whole-class discussions. Beatty and Gerace (2009) noted that "dialogical discourse within TEFA is intended to have several effects: to clarify thought through the process of articulation and externalization; to expose students to different points of view and lines of thinking; to promote analysis and resolution of disagreements; to supply stimuli, context, and tools for individual sense-making; and to provide practice speaking the social language of science. (p.155)" By engaging in the discussion and listening to other students' voices, they learn various perspectives and develop their thinking as a constructivist way.

3) Inform and adjust teaching and learning decisions with *formative assessment* (FA):

Several studies have emphasized the value of practicing FA for students' learning (e.g. Black and William 1998, 2005; Sadler 1989). Beatty and Gerace (1999) noted that "According to our cognitive dimension, students' initial beliefs and knowledge are idiosyncratic, as are their learning trajectories; a teacher needs detailed and current information about a student's thinking and state of understanding to efficiently facilitate the learning process, and this is obtained through FA. (p.156)" So, as the third polar of TEFA pedagogy, FA plays a role of continuator of the interaction between a teacher and students. In TEFA pedagogy, students vote their answers with clickers, and the classroom response system (CRS) shows a histogram result of the responses in a timely manner. This helps both the teacher and the students understand their status of understanding. In TEFA pedagogy, the purpose of using a histogram result is not for summative assessment, but for formative assessment for the teacher to examine students' understanding and find out the gap between students' thinking and the scientific concepts, so to develop students' reasoning through revisiting the concepts or revising their teaching practice.

4) Help students develop metacognitive skills and cooperate in the learning process with *meta-level communication*:

Beatty and Gerace (1999) noted that "We can say that most of the talk in a science class is discourse about the science content (or about administrative issues), but meta-level communication is discourse about *learning* the content. TEFA employs meta-level communication to (a) improve learning by increasing the efficiency of the instructional process, and to (b) improve the learner by promoting and scaffolding student development of more productive learning beliefs, attitudes, and behaviors. (p. 156)" TEFA pedagogy encourages teachers to talk about the goal and process of learning and to ask students their preferred way of learning and their purpose of learning.

With those four principles, TEFA pedagogy employs an educational technology, classroom response systems (CRSs). This plays an important role to encourage students to participate in class discussion. In TEFA pedagogy, there is a series of activities using a CRS, called a *question-cycle* (Dufresne, Gerace, Leonard, Mestre, & Wenk, 1996): teachers present multiple-choice or simple questions to class; students share their ideas as peers or work it individually; students vote their answers with *clickers* (CRSs); the CRS system shows a histogram result integrating students' responses immediately; students are engaged in whole classroom discussion based on the histogram result; and teachers clarify the concept with closure (Figure 1). In TEFA pedagogy, teachers play a role of facilitators of the discussion rather than instructors who simply convey information.

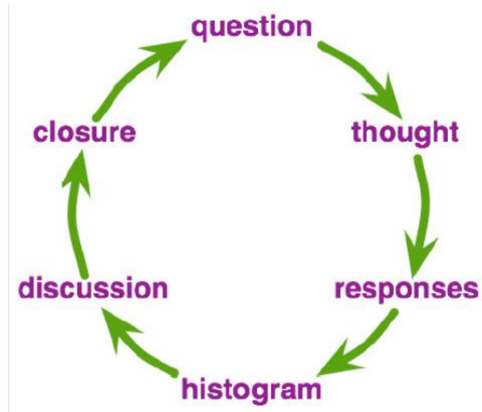


Figure 1: Question-cycle (Beatty, Feldman, Leonard, Gerace, St.Cyr, Lee, & Harris, 2008)

Similarities between TJ Instruction and TEFA Pedagogy

Although the TJ instruction and the TEFA pedagogy were developed in two different countries (one in Israel and the other one in the US) for different purposes (one focused on student learning and the other one focused on teacher change), the TJ instruction and the TEFA pedagogy share similarities (Figure 2): a) they both are discussion-oriented pedagogy; b) teachers guide the instruction and students generate their ideas, c) teachers play as facilitators of the discussion; and d) both employ a certain material (TJ uses images and TEFA uses CRSs) to give students motivation in learning and to encourage student participation in discussion.

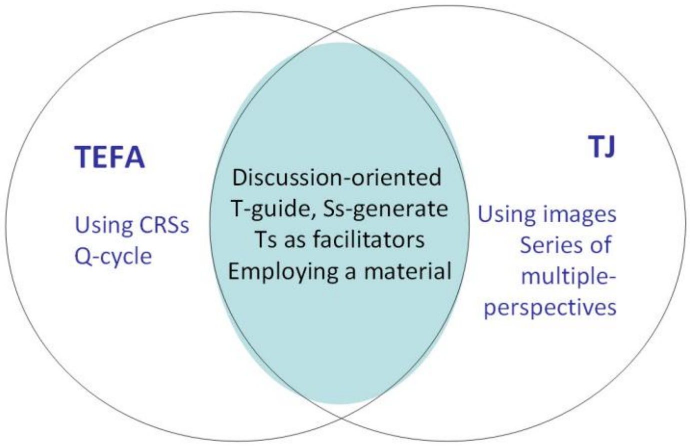


Figure 2: TJ instruction and TEFA pedagogy

Purpose of the Study

Those pedagogical similarities between TJ and TEFA and my own interest of using photographs in astronomy education are the basis of this study. For the study, I developed a curriculum unit that employed photographs and CRSs with the combined TJ+TEFA pedagogy. This study investigates pedagogical roles of photographs in science classes and reports various types of discourses that students and a teacher shared in the discussion-oriented pedagogy. In the next chapter, I look for literature that guides and frames my study: students' misconceptions about day-night and cause of seasons, visual representations in science education, the important aspects of constructivist learning, and classroom interaction and discourse.

CHAPTER 2

LITERATURE REVIEW

The intent of this literature review is to provide theoretical background of this study. My review is presented in four sections: first, I describe research of young students' misconceptions about day-night and cause of seasons; second, I review visual representations that are used in science education and studies about visual-spatial thinking; third, I review the studies about social constructivism and its impacts on teaching and learning; and fourth, I review studies about classroom interaction and discourse. Finally, I summarize what I found from the literature.

Misconceptions about *Day-Night* and *Cause of Seasons*

In constructivist view, students bring their ideas to the learning environment (Driver & Bell, 1986) that have formed from their daily experiences. This prior knowledge is called *preconception*, and is defined as "a conception in a certain area that is present in a student prior to instruction (Clement, 1993, p.1241)." The preconceptions are often incomplete and conflict with currently accepted scientific theory, and these are called *misconceptions (alternative conceptions)* (Clement, 1993). Not all preconceptions are misconceptions, but many preconceptions turn out to be misconceptions, and some are highly resistant to change even after competent instructions and they still remain as misconceptions (Clement, 1993). Studies of student understanding about the concepts of day-night and cause of the seasons have revealed that students often have strong misconceptions and they are resistant to change (Baxter, 1989, 1991; Comins, 2001; Jones, Lynch, & Reesink, 1987; Vosniadou, 1994; Vosniadou & Brewer, 1994).

Misconceptions about Day-Night

Baxter (1989) interviewed 100 students who were aged between 9 and 16 years, and found six notions of preconceptions about the concept of day-night: the sun goes behind the hill; clouds cover the sun; the moon covers the sun; the sun goes around the earth once a day; the earth goes around the sun once a day; and the earth spins on its axis once a day. Among the six notions, the last one is the correct one and the others are misconceptions. Dunlop (2000) surveyed 67 students aged between 7 and 14 from three schools that visited an observatory and studied their view of day-night, orbits, moon phases and seasons. In the study of day-night, he found that the common misconceptions were: the sun orbits the earth; the earth orbits the sun daily; the moon blocks the sunlight to cause night; and the moon causes night in a similar way to the sun causing day. Even after they learned the concept, only 20% of them mentioned the earth spinning or drew it spinning to cause day-night. Vosniadou (1994) studied children's ideas about this concept more deeply and found that their initial explanations were "embedded within a naïve theory of physics according to which the earth is flat, stationary, and supported physical object and the sun and the moon are located above its top (p.57)." The children's initial mental models were: the sun is occluded by clouds or darkness; the sun moves out into space; and the sun and the moon move up/down on the ground. Their initial models were caused by their existing conceptions about the earth's shape. For example, children often have a misconception that the earth is flat and stationary (Nussbaum & Novak, 1976). These initial models were often combined with the scientific model and resulted in a *synthetic mental model* (Vosniadou, 1994). Children attempted to assimilate aspects of the scientific model into their existing conceptual structures. Vosniadou (1994) found several synthetic mental models: the sun and the moon move up/down to the other side of the earth; the sun and the moon revolve around the earth once every da; the earth and the moon revolve around the sun every 24 hours; the earth rotates up/down or west/east; and the sun and the moon are fixed at opposite sides (Figure 3).

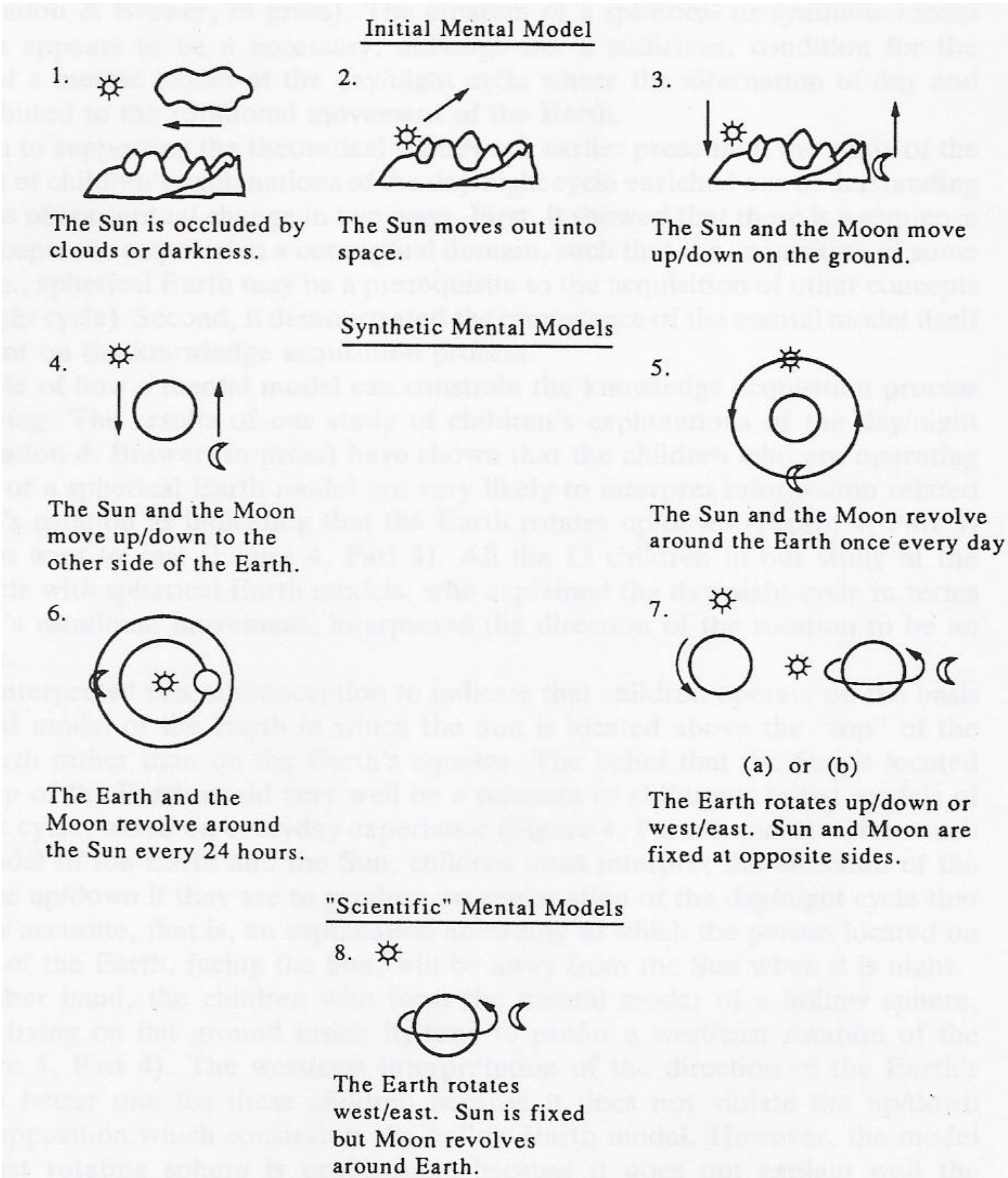


Figure 3: Students' mental models of the day-night cycle (Vosniadou, 1994, p57)

Misconceptions about Cause of Seasons

Baxter (1989) found six different notions about seasons in his study with 100 students: cold planets take heat from the sun; heavy winter clouds stop heat from the sun; the sun is further away from the earth in the winter; the sun moves to the other side of the earth to give them their summer; changes in plants cause the season; and seasons are due to the earth's axis being set at an angle to the sun. Again, all the notions except the last one are misconceptions. Dunlop (2000) found that children thought that the earth was divided into four quarters having different four seasons; seasons were caused by clouds blocking the sun in winter; and seasons were caused by the earth's distance from the sun. Among the three misconceptions, the last one is the most common misconception for many aged groups from young children to adults. For example, Atwood and Atwood (1996) reported that pre-service elementary teachers hold the misconception most commonly that the earth is further away from the sun in winter and closer to it in summer. It is also well known that the Harvard graduates had the same misconception as seen in the film, *A Private Universe* (Schneps, Sadler, Woll, & Crouse, 1989). This misconception is very resistant to change. Students still hold the misconception although they recognized that the earth's tilt is a very important factor for the seasons (Sadler, 1992).

According to the National Science Education Standards (National Research Council, 1996), the concepts of day-night and cause of seasons are one of the main goals for K5-8 science class;

> Objective K5-8: Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the Moon, and eclipses (p. 160). … The Sun is the major source of energy for

> phenomena on the Earth's surface, such as growth of plants, winds, ocean currents, and the water cycle. Seasons result from variations in the amount of the Sun's energy hitting the surface, due to the tilt of the Earth's rotation on its axis and the length of the day (p. 161).

As seen in the literature, however, students often have strong misconceptions about these concepts even after the instruction and bring their misconceptions to the higher grades, even until their adulthoods. Would there be any way that our educators can help them learn the concepts better? In the next, I introduce several studies about visual representations that have been reported to be helpful for student learning.

Visual Representations in Science Education

As modern technology grew up, educators began to focus on using various types of visual representations in educational settings. Visual representations in education vary from drawings such as charts, maps, diagrams, tables and graphs to more recent resources such as documentary movies, computer animations, simulations, and even video games. Visual representations often refer to external representations displayed on any medium (such as papers or on screen) that can be shared with others. The term *representation,* however, is also used to refer to mental content (e.g. Perner, 1991). Therefore, some researchers prefer to use the term *inscription* to avoid this ambiguity (e.g., Roth & McGinn, 1998). Originally, the term *inscription* had been introduced in the literature of sociology to distinguish representations between which exist in material form (therefore can be shared by several agents) and in mental representations (which are not accessible) (Roth & McGinn, 1998). Roth and McGinn (1998) argued that the term *inscription* emphasizes social aspect contrary to mental representations because *inscriptions* are publicly and directly available due to their material embodiment. On the other hand, recent studies in multimedia learning often use the term *pictorial modality* in terms of representational mode for a visual sensory organ (Mayer, 2001; Paivio, 1986).

Among the several different terms, I will use the term, *visual representations*, in the study because it is more widely and commonly used in education with less specific context. There have been various opinions and arguments about how visual representations help students learn the learning materials. Cook (2006, p1074) described the value of visual representations in his review:

> Visual representations attract attention and maintain motivation. They provide an additional way of representing information and foster the obtainment of knowledge that students may not get from text alone (Mayer, Bove, Bryman, Mars, & Tapangco, 1996). More specifically, visual representations enhance information retention of associated text (Peeck, 1993), improve problem solving, and facilitate the integration of new knowledge with prior knowledge (Roth, Bowen, & McGinn, 1999).

As a more empirical piece of evidence, Mayer found that students who listen to (or read) explanations represented solely as words without the aid of visual representations could not remember most of the key ideas well and had difficulties to solving new problems (Mayer, 1997, 1999a, 1999b, 2001). Visual representations may be more valued when teaching and learning science concepts. Cook (2006) noted that “they (visual representations) provide a means for making visible phenomena that are too small, large, fast, or slow to see with the unaided eye (p. 1074).” As can be seen in Buckley’s study (2000), visual representations can illustrate invisible or abstract scientific phenomena that cannot be directly observed. For example, imagine that you are learning the concept of reproduction of DNA from RNA. If you have to learn it only by reading texts, you may find difficulties understanding the concept and have to spend much more time to figure out what the texts mean than you would when a provided illustration describes the process. As another example, imagine that you are reading texts about how the earth is revolving the sun. Although the texts may also explain the sizes of the sun and the earth and the distance between them, it will be very difficult to conceptualize their relative sizes and the distance. But, if you can see some visual representations such as illustrations or animations (if it is described scientifically correctly), you will directly recognize the relative sizes of the sun and the earth and the distance between them. In other words, one piece of image can be representative for thousand words.

Understanding the value of visual representations is often discussed with *cognitive load theory* based on *Information Processing Theory (IPT).* The basic idea of IPT is that human mind processes information like the computer, working through logical rules and strategies but having a limited capacity (Gagné, 1985). According to IPT, the human brain has a sensory register that receives information. The information is stored temporarily in short-term memory unit and is processed in working memory. In the process of working memory, the information is decided whether to be discarded or to be stored permanently in long-term memory (Figure 4). When the working memory is overloaded, learning will not likely take place. This is often explained by *Cognitive Load Theory (CLT)* (Chandler & Sweller, 1991; Sweller, van Merrienboer & Paas, 1998).

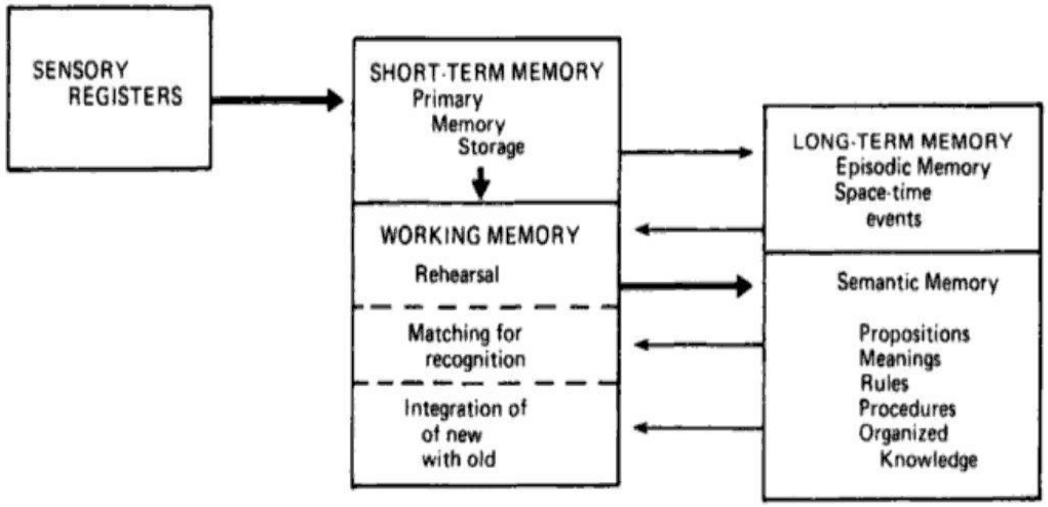


Figure 4: Human Information Processing (Gagné & Glaser, 1987, p55)

According to CLT, individuals have a different capacity of working memory which is determined by their *prior knowledge.* There have been many studies about reducing the cognitive load of working memory. Especially, recent computer-based learning studies have been focused to develop several principles about how to design computer simulation programs using various modalities to reduce cognitive load (Mayer, Heiser & Lonn, 2001; Mayer & Moreno, 2002a, 2002b, 2003). There are three forms of cognitive loads (Paas, Renkl, & Sweller, 2003). *Intrinsic cognitive load* is inherent to the learning material, determined by its element interactivity. When the elements of the learning material are highly interactive and cannot be isolated, it has a high intrinsic cognitive load. On the other hand, if the material is low at element interactivity, learning can occur with low cognitive load. The second form of cognitive load is *extraneous or ineffective cognitive load*. This is from poor instructional designs (Kirschner, 2002), which is unnecessary and interferes with schema acquisition (Paas, Renkl, & Sweller, 2003). The last form of cognitive load is *germane or effective cognitive load*. This is from instructional designs that contribute to the process of schema acquisition (Kirschner, 2002). Therefore, well-designed instruction with visual representation should be able to increase germane cognitive load and to reduce extraneous cognitive load. However, it is not true that learning will be maximized when the total level of cognitive load is too low. When the cognitive load is excessively low, learning can be degraded (Paas, Renkl, & Sweller, 2003). On the other hand, excessively high cognitive load can also impede learning. Therefore, the appropriate level of total cognitive load, by encouraging germane load and decreasing extraneous load within proper intrinsic load, should be carefully designed to obtain the goal of visual instruction.

Identifying the types and methods to accomplish the goal of visual representations became an interesting research issue in science education (e.g. Hegarty, 2004; Lewaler, 2003; Lowe, 1993, 2003; Mayer, Heiser & Lonn, 2001; Mayer & Moreno, 2002a, 2002b). The most general distinction for visual representations would be whether it is *static* or *dynamic*. Static visual represents the images such as diagrams, illustrations, graphs, pictures, photos, or any types of non-movable scenes of images. Dynamic visual represents the movable scenes of images such as movies, animations or simulations. They both have merits and limitations in teaching and learning. Dynamic visuals may be superior to represent motions or process than statics (Park & Hopkins, 1993), but it (dynamics) may require excessively high cognitive loads to students (Lowe, 1999, 2003). On the other hand, although static visuals have limitations to represent the motion or 3-dimensional space, it may give students more space for working memory, encouraging reasoning and thought process. In the next, I describe studies about photographs, which is a static visual representation.

Photographs as Static Visual Representation

Myers (1988) described that photographs "are full of *gratuitous detail* and present the background as a space continuous with our own (p239)." Figure 5 shows a spectrum of gratuitous details with the categories of pictures, described by Myers (1988). Photographs have the most, but graphs or simplified diagrams have the least gratuitous details. Myers (1988) noted that "photographs come with apparent self-evidence, because they are taken as mechanical reproductions of an image (p239)." Pozzer-Ardenghi and Roth (2005) also noted that "photographic detail provides a space that is continuous with the lived world, allowing viewers to establish a link with the everyday world that surrounds them (p277)." Due to this characteristic, photographs often give us strong message about the real world. As an example, we realize the unfairness of a war or poverty by looking at a Pulitzer Prize-winning photograph, which remains much stronger in our minds than reading a lengthy article or an argument. As can be seen in the word, *photovoice*, photographs have the powerful role to represent the real world in social issues (for more information about photovoice, http://www.photovoice.org). Therefore, studies about photographs have been mainly conducted in sociology (Berger, 1972) or in communication (Livingston, 1995), but there have been very few studies in science education.

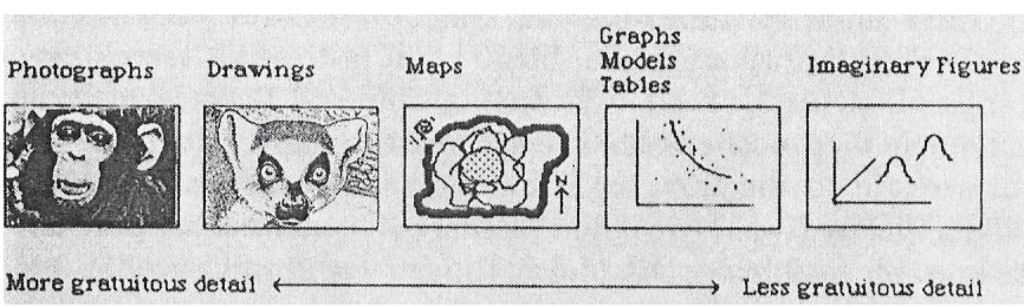


Figure 5: Spectrum of gratuitous detail (Myers, 1988, p238)

Studies about photographs in science education are limited to textbook contexts (Roth, Bowen, & McGinn, 1999). Pozzer and Roth (2003) distinguished four functions of photographs in relation to captions and texts in high school biology textbooks: *illustrative,* "having a caption that names the object or phenomenon represented in the photograph, but no additional information is available"; *decorative,* "lacked caption and indexical reference in the text"; *complementary*, "with caption that names the represented object or phenomenon and provides new information not available in the associated main text"; and *explanatory,* "having captions that name the represented object or phenomenon and provide relevant explanations or classifications" (all quotes from Pozzer-Ardenghi & Roth, 2004, p. 222).

In their later study (Pozzer-Ardenghi & Roth, 2004), they found that "decorative photographs, without captions, proved to generate greater difficulty in associating photograph and text, as this association becomes subjective when explicit links (such as caption and indexical reference, for example) are missing (p. 236)." They also found that: "one of the major functions of photographs is to capture readers' attention (p. 237)", "main texts are certainly an important resource in helping the readers to interpret the photographs (p. 237)", and "students pay attention to the indexical references to the figure when reading a textbook (p. 237)." They noted that providing more specific directions, such as arrows or colored areas, is needed in science textbooks to help students to identify the right details to be observed in the photographs.

Another interesting study performed by Pozzer-Ardenghi and Roth (2005) was about gestures when photographs were presented in lectures. They categorized eight different functions of a teacher's gestures and body orientations that they found to help learners interpret photographs in science lectures: representing, emphasizing, highlighting, pointing, outlining, adding, extending and positioning. These gestures constitute a range of semiotic resources that are not normally available in textbooks and allow the audience to appropriately connect photographs and verbal texts, therefore they play an important role in science discourse (Pozzer-Ardenghi & Roth, 2005).

Thinking Journey is a new teaching mode that uses photographs out of textbook context (Schur, Skuy, Zietsman & Fridjhon, 2002). TJ instruction is designed to encourage discussion between students and a teacher in the context of an imaginary journey. Photographs in TJ show students different perspectives. TJ instruction provides students with several *pictures* to *observe* and *compare*, giving them *different perspectives*, and emphasizes developing *dialogue* between students and the teacher, resulting in the improvement of their *conceptual* understanding. In their study, they reported an empirical evidence that this TJ instruction contributed to students overcoming their egocentric view, promoting dialogue in classroom, undergoing conceptual change, and motivating them to learn the concept (Shapiro, 2007).

In many science textbooks, astronomical photographs are often used as the decorative function due to their beauty. Although the photographs can imply much more than that, they are often ignored in science class. Although the gratuitous details of the photographs could be a good pedagogical resource, they have been little valued in science education. Therefore, the TJ method that gives students different perspectives with the use of photographs was an innovative idea. Then, would just showing the photographs to students be enough? What has to be the purpose of using the visual representations in student learning? In the next, I review literature about visual-spatial thinking.

Visual-Spatial Thinking

Students often fail to describe an astronomical concept correctly especially when it involves spatial elements. For example, to understand the concept of the phases of the moon, students need to apprehend the nature of shadows, reflections, relative motion and frame-of-reference orientation (Taylor, 1996). It is often observed that even adults as well as young children rarely understand this concept correctly. It is not only because it has an excessively high intrinsic cognitive load, but also because people have been indifferent to develop *visual-spatial thinking* (Mathewson, 1999).

Mathewson (1999) described that "visual-spatial thinking includes *vision*- the process of using the eyes to identify, locate, and think about objects and orient ourselves in the world, and *imagery*-the formation, inspection, transformation, and maintenance of images in the mind's eye in the absence of a visual stimulus (p34)." Such as in the TJ instruction that photographs are shown, students experience a series of process such as: looking at the photographs, carrying out their prior knowledge, interpreting the photographs based on their prior knowledge, connecting it (interpretation) with their real life, and generating a newly formed concept. Their prior knowledge affects them to interpret the photographs. In other words, "perception is not independent of memory. ... When a perceptual image is formed by the eye, it is automatically compared to information already in our unconscious memories (Mathewson, 1999, p34)." Individuals may interpret the same picture differently, and these different ways of seeing (Berger, 1972) can confuse students (Pozzer-Ardenghi & Roth, 2004). However, how much has our school been concerned about different ways of seeing? How much have we been concerned about students' misconceptions that are generated by different ways of interpretation from the vision? How much has our curriculum been focused to develop students' visual-spatial thinking?

Mathewson (1999) argued that there has been a lack of visual communication in educational settings and schools have mainly focused to teach children how to *read* and *write*, emphasizing raising their verbal ability. Arnehim (1969) also argued that:

> Purely verbal thinking is the prototype of thoughtless thinking, the automatic recourse to connections retrieved from storage. It is useful but sterile. What makes language so valuable for thinking, then, cannot be thinking in words. It must be the help that words lend to thinking while it operates in a more appropriate medium such as visual imagery (p231-232).

It is well known that a famous scientist such as Albert Einstein used highly visual thought experiments to explore his ideas. Then, are people born with a visual-spatial thinking ability? Does this mean it can never be improved? Should a high visual-thinking ability be the mastery for only few "genius" scientists? With the evidence of Neisser's study (1997), Mathewson believed that with training and practice, performance on spatial tasks can be improved. And, he noted that:

> Elaborately illustrated books, overhead projector transparencies, videos, CDs, and computer programs are produced in abundance, but the merits of the visual-spatial aspects have been taken for granted or judged inexpertly by most users. A scattered literature and expertise on visual communication exists in a variety of fields such as advertising, artificial intelligence, cartography, cognitive science, computer graphics, design, educational technology, information science, industrial psychology (human/machine interfacing), science illustration, and so on. The national education reform programs should consider projects for evaluating the merits of classroom visual-spatial material and activities that can pull together these scattered resources (p43).

Mathewson (1999) also argued that "visual-spatial activities should be a preferred way to address the usual list of science processes (observing, communicating, comparing, ordering, categorizing, relating, interring) (p45)" and "visual-spatial thinking ought to be a systematic and integral part of planning, teaching, teacher preparation and research in education (p49)."

I believe students can improve their visual-spatial thinking through appropriate school instruction. And, the use of visual representations in school science class should focus to develop students' visual-spatial thinking as well as to be helpful for students' understanding. The instruction with visual representations should include developing students' process skills such as observing, comparing, communicating, ordering, categorizing, relating and interring, as Mathewson mentioned.

What kind of instruction would be desirable for students to develop process skills as well as content knolwedge? In the next, I describe studies about constructivism and its impacts on learning and teaching in science education.

Constructivism

In traditional science class, the role of a teacher was often considered to convey information to students. In my memory, my school teachers were always standing in front of the class and *teaching* subject matters. And, my classmates and I were busy writing down what they told us. There was no interaction between the students and the teachers. There were only content goals that we needed to learn, but there were little process goals of how we could develop our thinking. Therefore, learning was mainly performed by rote memorization. Although I could earn good grades, I think my knowledge was more superficial and not very deep. This type of knowledge is very fragile. There exist only either *correct* or *wrong* answers, so students are often reluctant to raise their hands to answer a teacher question. In this type of class, students become passive learners. On the other hand, when I was a high school student, I had a great experience. One day, my friends and I were staying at school, doing a physics homework assignment together. It was a classical mechanics problem and one of my friends and I had different ideas. Our discussion continued for several hours until sunset. We both learned a lot from the discussion, and I remember that I wished our science class could have been the place for us to have this type of discussion. I have since realized that this type of learning is called *social constructivist* learning. In the social constructivist learning, students become active learners. Students' responses do not have to be correct or wrong because they are all part of learning activity. Teachers no longer perform frontal teaching, but they *facilitate* class discussion.

In history, constructivism is divided into three main streams: cognitive constructivism, radical constructivism, and social constructivism. *Cognitive or Piagetian constructivism* describes how children develop cognitive abilities with different stages by different ages (Piaget, 1950). Piaget's theory of cognitive development proposes that humans cannot be given information, which they immediately understand and use. Instead, humans must construct their own knowledge. "Knowledge acquisition is an adaptive process and results from active cognizing by the individual learner. … Knowledge is the result of the accurate internalization and (re)construction of external reality (Doolittle, 1999)."

Radical constructivism (von Glasersfeld, 1984) represents the opposite end of the constructivist continuum from cognitive constructivism. This theory "emphasizes leads to defining principles that maintain the internal nature of knowledge and the idea that while an external reality may exist, it is unknowable to the individual (Doolittle, 1999)". In radical constructivism, "while knowledge is constructed from experience, that which is constructed is not, in any discernible way, an accurate representation of the external world or reality (von Glasersfeld, 1995)."

Social constructivism originated with Vygotsky (1978). He suggested that learning is the result of social interaction occurred within *zone of proximal development (ZPD)*. ZPD is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers (Vygotsky, 1978, p. 86)." In other words, ZPD is the difference between what a learner can do without help and what he or she can do with help. According to Vygotsky, a learner can learn better when he or she is in their ZPD, and the role of education is to provide learners with experiences which are in their ZPD, thereby encouraging and advancing their individual learning (Berk & Winsler, 1995). Bakhtin (1984) noted that "truth is not to be found inside the head of an individual person, it is born between people collectively searching for truth, in the process of their dialogic interaction." Truth is a socially constructed and agreed upon result from "co-participation in cultural practices (Cobb & Yackel, 1996)." Social constructivism emphasizes the co-construction of meaning within a social interaction. Therefore, social constructivism "lies between the transmission of knowable reality of the cognitive constructivist, and the construction of a personal and coherent reality of the radical constructivists (Doolittle, 1999)." Driver and Bell (1986) viewed learning in social constructivism and defined that:

1) Learning outcomes depend not only on the learning environment but on what the learner already knows. Students' conceptions, purposes and motivations influence the way they interact with learning materials in various ways.
2) Learning involves constructing meanings. Meanings constructed by students from what they see or hear may or may not be those intended. Construction of a meaning is influenced to a large extent by our existing knowledge.
3) The construction of meaning is a continuous and active process.
4) Meanings, once constructed are evaluated and can be accepted or rejected.
5) Learners have the final responsibility for their learning.
6) Some meanings are shared. There are patterns in the types of meanings students construct due to shared experiences with physical world and through natural language.

In the social constructivist view, students bring their ideas into the class, and this prior knowledge affects their learning. This may also happen when they interpret a visual representation.

Based on the social constructivism, collaborative learning became an important issue in education. According to Gokhale (1995), "the term, *collaborative learning*, refers to an instruction method in which students at various performance levels work together in small groups toward a common goal. The students are responsible for one another's learning as well as their own. Thus, the success of one student helps other students to be successful (p.22)." Collaborative learning is an approach to teaching and learning in which students are required to work together in the learning process, and to reach a consensus through negotiation to accomplish group tasks (Bruffee, 1993). Students form a group, so that students with different relevant skills are brought together to work out a solution to the problem, and the work group draws out a consensus solution which takes account of each student's perspectives. There is a merit that students can build their collaborative knowledge by seeing other students' perspectives. Students can learn "multidimensional thought" and they can become "flexible or open-ended" learners

(Lobel, Neubauer, & Swedburg, 2005). The collaborative learning process encourages knowledge construction in an environment in which learners are sharing their own understanding and trying to negotiate a shared understanding. They become aware of the existence of multiple points of view, and that advanced knowledge construction needs to take these into account. In this way, students learn from their peers as well as their teachers (Jonassen, Mayes & McAleese, 1993). Johnson and Johnson (1986) also showed an empirical evidence that students who worked as groups achieved higher levels of thought and retained information longer than students who worked individually.

Social constructivism gave an impact on teachers' methodology as well. Black and Wiliam (1998) raised an issue of the value of formative assessment. They argued that "teaching and learning must be interactive. Teachers need to know about their pupils' progress and difficulties with learning so that they can adapt their own work to meet pupils' needs -- needs that are often unpredictable and that vary from one pupil to another. Teachers can find out what they need to know in a variety of ways, including observation and discussion in the classroom and the reading of pupils' written work (p.140)." By interacting with students, teachers can know what prior knowledge students have brought to class, what misconceptions they have, and where the teacher needs to cover more to help the students' understandings. According to Cowie and Bell (1999), teachers perform two types of formative assessment. One is *planned formative assessment* that teachers elicit and interpret assessment and take action during whole class. The other one is *interactive formative assessment* that teachers notice, recognize and respond to individual students or small groups. Although interactive formative assessment can be naturally performed in class, teachers often reveal their difficulties to perform planned formative assessment for whole class. This may be because students feel more comfortable to talk in small groups than in a whole class. It may be also difficult for teachers to understand all the students' ideas and respond to them in a timely manner in a whole class.

The recent modern technology, classroom response systems (CRSs), may help teachers with performing planned formative assessment. CRS is now widely adaped in many college teaching in US. This technology was implemented in secondary science classes in the *Teacher Learning of Technology-Enhanced Formative Assessment (TLT)* project at the University of Massachusetts Amherst. Science and mathematics teachers in local secondary schools had participated in three-year professional development and used CRSs in their classes. After 1~2 years, their practice had changed and practiced more formative assessment than before they had used it (Beatty et al., 2008). Recent studies showed that students have positive attitudes toward using CRS in class. In a survey of 8,000 students at the University of Massachusetts Amherst, 80% of the students responded that their CRS experience was positive and wanted the instructor to keep use CRS (Rogers, 2003). Trees and Jackson (2003) reported that in a survey with 1,500 CRS users most students thought that the CRS gave them valuable feedback and enjoyed the interaction that the CRS provided. Newport (2004) also reported that students felt more involved in class discussion when CRS was used. When CRS is used effectively, it can attract students into active participation, help students integrate new knowledge and overcome misconceptions by making them conscious of their own background knowledge and preconceptions, clarify students' thinking, discover students' gaps and contradictions in their understandings, and identify flaws in students' logic (Beatty, 2004). CRS has the applicability of formative assessment in a real-time class and facilitate classroom discussion (Feldman & Capobianco, 2003).

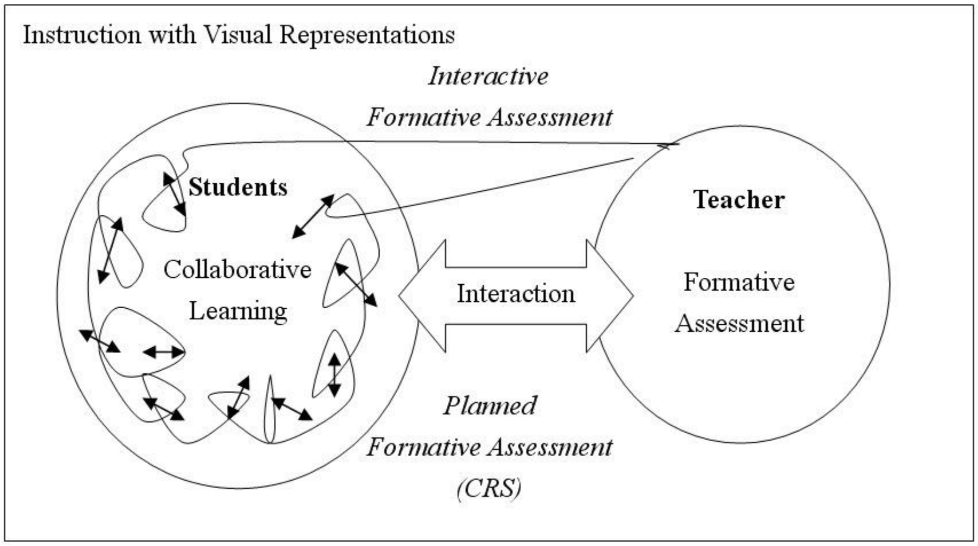


Figure 6: Ideal instruction based on social constructivism

I believe, to maximize student learning, the instruction with visual representations should be performed in the context of social constructivism. Figure 6 summarized what I have written in this section. In the basis of constructivist view, students work collaboratively and teachers facilitate class discussion by interacting with students. Teachers perform interactive formative assessment for individuals or small groups and do planned formative assessment with the help of CRS for whole class.

Classroom Interaction and Discourse

Then, how can we help students develop their thinking in the social constructivist way? How would the class look like in the social constructivism? In this section, I overview studies of classroom interaction and discourse that focus on social constructivist aspect of teaching and learning.

Teacher Questioning

In traditional class, teacher talk is authoritative and tends to convey information. Chin (2007) noted that in such traditional class, “Teacher talk often involves factual statements, reviews, and instructional questions, and students’ responses to the teacher’s questions typically consist of single, detached words (p.816).” On the other hand, in constructivist class, teacher talk has dialogic functions. Chin (2007) noted that in such dialogic discourse, “the teacher encourages students to put forward their ideas, explore and debate points of view, and students’ responses are often tentative suggestions based on open or genuine questions, spontaneous, and expressed in whole phrases or sentences (p.816).” The class is more interactive in the latter than the former, and how teachers talk in class affects classroom discourses.

One of the typical classroom discourses may be the *Initiation-Response-Evaluation (IRE)* pattern (Mehan, 1979). This is a simple questioning sequence between a teacher and a student (T-S-T). Mortimer and Scott (2003) expanded this by identifying the *Initiation-Response-Feedback-Response-Feedback (IRFRF)* chain. In this chain, there is a series of interactions between the teacher and students (T-S-T-S-T). In this discourse pattern, teachers can encourage students to continue and to develop their thinking. One of the teacher talks that can enhance IRFRF chain is the *reflective toss*. The idea of reflective toss is that the teacher’s question catches the meaning of the students’ statement and throws responsibility for thinking back to students, so the students can elaborate their ideas (van Zee & Minstrell, 1997a). Van Zee and Minstrell (1997b) used the term, *reflective discourse*, to refer “vigorous interactions among students and teachers (p.209).” They noted that;

> We define reflective discourse as group discussions in which students express their own thoughts in comments and questions rather than recite textbook answers; the teacher and individual students engage in extended series of questioning exchanges that help students articulate their beliefs and conceptions; and students/students exchanges involve one student trying to understand the thinking of another. (p.212)

The reflective discourse is neutral restatements of the preceding student's utterances or summarization what the student just said. Teachers do not use evaluative responses, but instead they express like "ok?", "good", "yeah", or "great, but why do you think …?", etc.

Teachers can enhance the reflective discourse with the use of various types of teacher talk. Chin (2007) investigated teacher questioning approaches that can stimulate the reflective discourse and students' productive thinking: *Socratic questioning* is "a series of questions to prompt and guide student thinking and reflective toss is the one of the Socratic questionings"; *verbal jigsaw* "focuses on the use of scientific terminology, key words and phrases to form integrated propositional statements"; *semantic tapestry* "helps students weave disparate ideas together into a conceptual framework,"; *framing* uses "questions to frame a problem, issue, or topic and to structure the discussion that ensues" (p.823). The purpose of those questioning is to support students generating their thinking.

As other type of teacher questioning, there is *discrepant questioning* (Rea-Ramirez, Nunez-Oviedo & Clement, 2009). This is to produce dissatisfaction with an idea that is generated. This leads students to see contradictions in their own model and to modify it to get close to the scientific conception. Lastly, there is a *devil's advocate*, which asks students an opposite question to confuse them after they have already built the right conception. By this process, the students can have much deeper and more stable understanding.

Conflict Map

Teachers can employ a sort of instruction that has a similar function of discrepant questioning. For example, Tsai and Chang (2005) employed *Conflict Map* to address students' conceptual change about the concept of cause of seasons. In their instruction with the conflict map, students faced two types of conflicts to experience conceptual changes: one occured between students' alternative conception and a new perception (conflict 1), and the other one occured between students' alternative conception and the scientific conception (conflict 2). Conflict 1 can be resolved through *discrepant events*, and conflict 2 can be resolved through *critical events or explanations* and relevant perceptions and conceptions that clearly explain the scientific concept. They differentiated discrepant events and critical events; "in the case of a discrepant event, students are confronted with an unfamiliar, new finding, whereas, in the case of a critical event, the students are invited to make an inference that contradicts a fact that is already well known to the learners or in the context of their cultural experiences (p.1091)." In addition to these discrepant events and critical events, conflict map used other relevant perceptions or conceptions that support the target scientific concept, which suggested teachers let students recognize the fact that in June/July, the earth is slightly further from the sun and in December/January, the earth is closer to the sun, and that people in northern hemisphere experience hot summer in June/July (*discrepant event*). As a next step, teachers encouraged the students to infer that if seasons were caused by earth's distance to the sun, the Northern and the Southern Hemispheres would have had the same season at the same time, but it was not true because when the Northern Hemisphere is winter the Southern Hemisphere is summer and vice versa (*critical event*). As other relevant conceptions or perceptions, concepts of earth's rotation, concepts of perihelion and aphelion, and perceptions of the length of daytime and warm Christmas in Australia and New Zealand supported students's understanding about the scientific concept (Figure 7).

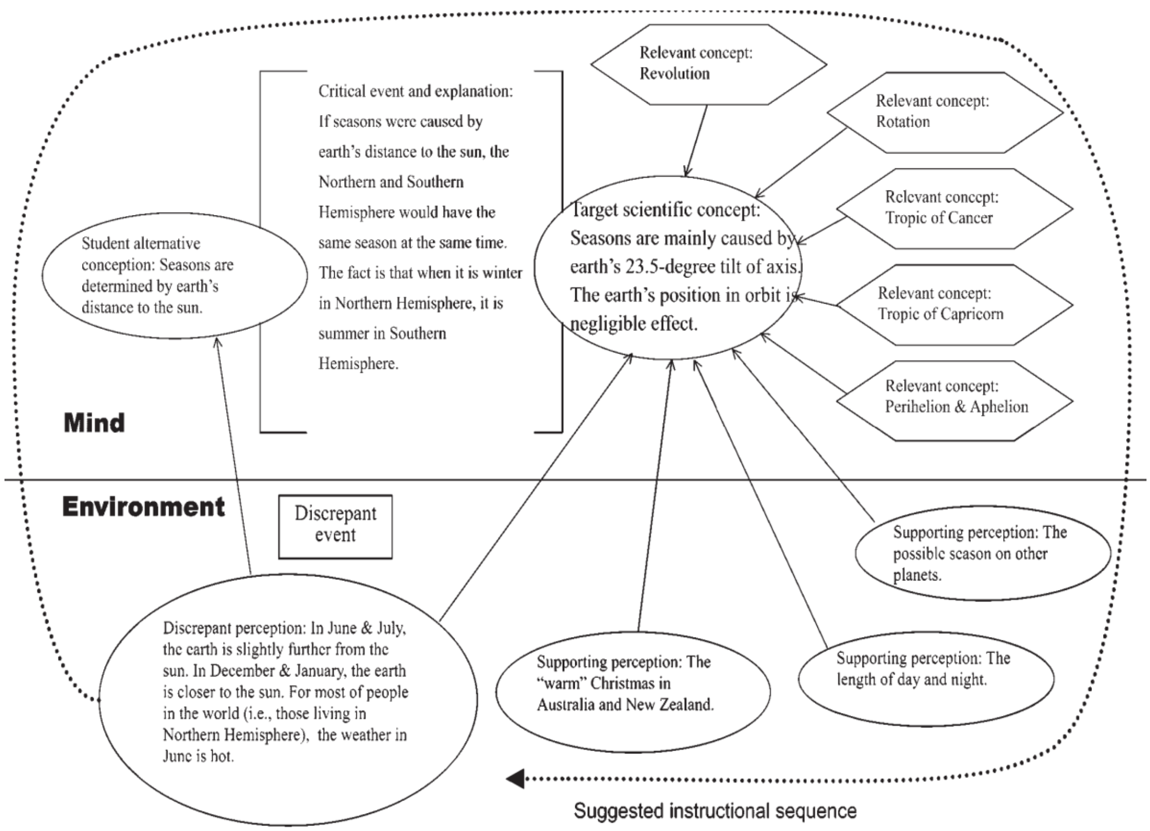


Figure 7: Conflict map of seasonal change on earth (Tsai & Chang, 2005, p1094)

In the conflict map, teachers mostly generated ideas, and the interaction was mostly happened between a teacher and students. There is another type of interaction in class, which is between student and student. If teacher questioning plays an important role in the teacher-student interaction, teachers give a minimal intervention in student-student interaction. In the next, I review studies about argumentation, which is an example of student-student interaction, in science education.

Argumentation

What is *argument*? According to the American Heritage Dictionary of the English Language (Third Edition, Electronic version), argument is described as "a discussion in which disagreement is expressed, or a course of reasoning aimed at demonstrating truth or falsehood." Driver, Newton and Osborne (2000) saw this interpretation of argument as "being used to tell others and to persuade them of the strength of the case being put (p291)" and "as one-sided and has limitations in educational settings (p291)," because this can be "common in science lessons in which a teacher provides a scientific explanation to a class or to a group of students with the intent of helping them to see it as reasonable (p291)." The other type of interpretation of argument is *dialogical* or *multivoiced* that is "involved when different perspectives are being examined and the purpose is to reach agreement on acceptable claims or courses of action (p291)" and that "can take place within an individual or within a social group (p291)." This differs from the earlier one-sided view and emphasizes social interaction. Therefore, this is more valued in science education.

Argumentation theory has been developed over several decades and one of the most important contributors is Stephen Toulmin who is a British philosopher and educator. He proposed in his book, *The Uses of Argument* (1958), six components for analyzing arguments:

Claim: a conclusion whose merit must be established.

Evidence (Data): a fact one appeals to as a foundation for the claim.

Warrant: a statement authorizing a movement from the data to the claim, reasons (rules, principles, etc.) that propose to justify the connections between the data and the knolwedge claim, or conclusion.

Backing: basic assumptions, usually taken to be commonly agreed that provide the justification for particular warrants; backing must be introduced when the warrant itself is not convincing enough to the readers or the listeners.

Rebuttal: statements recognizing the restrictions to which the claim may legitimately be applied; specify the conditions when the claim will not be true.

Qualifier: words or phrases expressing the speaker's degree of force or certainty concerning the claim; specify the conditions under which the claim can be taken as true, representing limitations on the claim. Such words or phrases include "probably," "possible," "impossible," "certainly," "presumably," "as far as the evidence goes," or "necessarily."

In science education, this Toulmin's model has been used as a tool to analyze students' argumentation for categorizing the pattern or assessing the quality of it (ex. Erduran, Simon & Osborne, 2004). Studies about argumentation in science classes have shown that this could foster scientific thinking (Kuhn, 1993) because this helped students wrestle with scientific concepts more effectively as they socially construct them.

In this section, I described studies about teacher questioning, conflict map as one dissonance strategy that teachers can use, and argumentation that students can do in class discussion. Besides those issues, there are other interesting issues relating to classroom interaction or discourse such as student interaction in small groups (Webb, 1982) or strategies that can enhance classroom discourse such as co-construction model (Clement, 1989), however, those are beyond the scope of this study.

Summary

In this literature review, I reviewed studies about misconceptions of day-night and cause of seasons; visual representations in science education; constructivism; and classroom interaction and discourse. According to the literatures, the following ideas are found:

- Students often have strong misconceptions about the concepts of day-night and cause of seasons. And, the traditional teaching method may not be helpful for the students to promote their conceptual change.
- Although several studies investigated students' misconceptions about those concepts, few studies have focused on developing a curriculum or an instruction that implements visual representations or educational technology that helps students learn those concepts better.
- Although most astronomical concepts including day-night and cause of seasons require students with visual-spatial thinking, there has been a lack of instruction to develop this ability.
- Visual-spatial thinking should include the list of process skills such as observing, communicating, comparing, ordering, categorizing, relating, and interring.
- Although photographs are the most common visual representation that students can see in class (mostly through their science textbooks) and in daily lives, their value has been payed little attention to pedagogical purposes.
- Cognitive load is lessened when the new scientific concept is connected to students' prior knowledge.

- According to the social constructivist view, discussion is a very important factor in students' learning. There is a value of students' collaborative work and teachers' formative assessment.
- CRS can encourage students' participation in class discussion and help teachers perform planned formative assessment for whole class.
- Teachers can enhance classroom discourse in science classes with the use of proper questionings such as reflective toss, Socratic questioning, discrepant questioning or a strategy of conflict map.
- Argumentation can foster students' scientific thinking.

Photographs can be a great resource in science education because they are full of gratuitous details and capture the moments of our real world. By using photographs, students may be able to connect their prior knowledge to a new scientific concept, lessening cognitive load. In the process of observing, and seeking the scientific meaning of it, students will be able to develop their visual-spatial thinking. In many science classes, students usually learn scientific concepts as being (already) simplified (and abstracted) model, helping them to easily digest them. However, when they meet them in a real life, some of them even do not recognize the relation between what they learned in class and what they experience now. And, many students do not know how to start, how to approach the problem and how to simplify it because they have not learned how to do so. In other words, science educators have mainly focused on how well we can feed students by seeking a way for them to digest by grinding, cutting, frying in oil, boiling, steaming or fermenting, but had little attention to how to help them start and develop their ability to make their own food by themselves.

CHAPTER 3

RESEARCH DESIGN AND PROCEDURES

According to the findings from the literature, I developed lessons for the topics of *day-night* and *cause of seasons* for middle school science classes that employed discussion-oriented pedagogy. One middle school teacher, Mary, and her 6th grade students participated in this study. I collected various data such as classroom observations with videotaping, student pre-post conception tests, student attitude surveys and teacher interviews. Grounded theory approach, descriptive statistics and t-tests were used to analyze the data. In the below, I describe with more details the development of the curricular unit, research questions, setting and participants, data collection and analysis.

Development of a Curricular Unit for *Day-Night* and *Cause of Seasons*

In the context of the TLT project with myself as a graduate research assistant, I looked for a teacher who was teaching astronomy and participated in the TLT project. Astronomy is not considered as a "major" science subject, unlikely to physics, biology, or chemistry, and is often covered only partly in earth science or physics classes. Therefore, it was very difficult to find an astronomy class. Among the over 40 teachers from several secondary schools in the northeastern US who participated in the TLT project, there was no one teaching high school astronomy in any science class. Luckily, however, there was one teacher, Mary, who taught middle school astronomy, and she happily agreed to participate in my study. She majored in sociology in undergraduate and elementary education in graduate school. She taught in an elementary school for 3 years, moved to this middle school, and had been teaching earth science for the grade 6 for over 10 years. She had often participated in summer schools and professional development programs to learn science teaching. The earth science class that she taught was for one year, and astronomy took part of the entire fall semester.

Choosing Topics

The textbook she used for the astronomy class was Silver Burdett Ginn's *Science Discovery Works: The Solar System and Beyond* (Badders, Bethel, Fu, Peck, Sumners, Valentino & Mullane, 1996), and it consisted of several important basic concepts in astronomy from constellations to galaxies. In addition to the textbook, she used other resources such as Internet websites or worksheets from other textbooks. There was a certain set of curriculum suggested by the school district that needed to be covered in the astronomy class during the semester (Table 1). When I had a meeting with her to discuss the set up of the study and to hear her opinions about teaching the concepts, she said that the most difficult concepts to teach were day-night pattern and the cause of seasonal changes[1]. She said that students did not seem to gain any knowledge and there seemed little change in their understanding of the concepts even after having instruction (especially for the concept of cause of seasons). She said that she had tried to find a better way of teaching those concepts but it was not so successful. Therefore, she expected me helping her teach those concepts in a new way so that her students could have a possibility to learn the concepts better.

Developing the Curricular Unit

I wanted to develop lessons with the TJ instruction and the TEFA, and the TJ instruction was originally developed for the concept of day-night cycle. In addition, Mary

[1] She also mentioned the concept of "the phases of the moon" as a very difficult concept to teach. But this was not considered in my study.

Table 1. Standard curriculum for the grade 6 astronomy at the district in northestern US

Astronomy: Upon completion of Grade Six, the students will be able to:
◦ Identify the major constellations by their position in the sky.
◦ ‡ Explain how the motions and orientation of Earth and its moon cause the cycles of day and night, seasons, eclipses, and phases of the moon.
◦ Name and identify the purpose for various instruments used by astronomers, such as the reflecting, refracting, radio telescopes, and spectroscope.
◦ † Explain how the movement of Earth causes the apparent motion of stars as observed from Earth.
◦ Differentiate between the various objects in the solar system, such as planets, moons, comets, meteors, and asteroids.
◦ Describe the life cycle of a star.
◦ Identify characteristics of galaxies in the universe.
◦ Describe the ways in which humankind has benefited from space exploration.
▪ State specific ways in which technology milestones have altered the history of astronomy and list inventors who have contributed to the development of technology.
▪ Create a database for organization of data regarding the various objects in the solar system, such as planets, moons, comets, meteors, and asteroids.
▪ Manipulate the category layout within an "astronomy database" for easy data entry.
▪ Use an online database to research the characteristics of galaxies in the universe.
▪ Use a student created database about objects in the solar system to generate a report that displays specific information.

▪ : Technology-related activity (optional)
†: This is a topic that she felt difficult to teach.
‡: This is a topic that she felt "very" difficult to teach.

was looking for a new way to teach the concepts of day-night and cause of seasons. Therefore, it was natural to set the topics to the concepts of day-night and cause of seasons for my study.

In developing the lessons, I closely worked with Mary and the TJ Israeli group researcher, Dr. Schur. Mary gave me general comments about the age level for the degree of the difficulty of the lessons, and Dr. Schur gave me comments on conceptual questions and about the TJ method in the lessons. After revising the lessons several times based on their comments, the final version of the 2-week curricular unit was developed (Appendix A). Student activity worksheets were developed to accompany the lessons (Appendix B).

Structure of the Curricular Unit

The unit has three different sections: 1) day-night cycle; 2) bridging concepts between day-night and seasonal change; and 3) cause of seasons. Table 2 summarizes the main structure of the curricular unit.

Table 2. Structure of the curricular unit

Day-Night cycle	▪ Introduction: Sunlight, Shadows, & Temperature ▪ Modified TJ instruction for day-night ▪ Direction of the rotational axis of the earth
Bridging between the day-night cycle and cause of seasons	▪ Phenomena: Polar Darkness and White Night ▪ Different length of daytime and nighttime ▪ Tilted rotational axis of the earth
Cause of seasons	▪ Checking prior conception ▪ Suspecting a strong prior conception (using a discrepant event; Tsai & Chang, 2005) ▪ Building a new concept: angle of the surface, different length of daytime ▪ Application and Closure

The lessons employed photographs with multiple-choice conceptual questions to be used with CRSs. The TJ original instruction for day-night that had been used in Israel was modified to be TEFA multiple-choice conceptual questions (see “TJ mode” part in Appendix A). The lessons also employed small group work, discussion and presentation, hands-on activity with a globe and a light bulb, and teacher demonstrations as well as whole classroom discussion.

Research Questions

There are three research goals of the study.

Research Goal 1: To investigate student interaction with a teacher when learning with photographs and CRSs in the discussion-oriented pedagogy.

The kind of lessons that implemented CRSs and photographs is new and very little is known about the types of discourses between students and a teacher when using a curriculum with photographs and CRSs. This study provides a key to understanding the dynamic interaction between the students and the teacher in such an innovative pedagogy implementing photographs and CRSs. In order to pursue this goal, the following specific research questions (RQs) were answered:

RQ1.1. What are the types of discourses that students engage in while they are participating in classroom discussion when learning with photographs and CRSs?

RQ1.2. What are the types of discourses that a teacher engages in while she is facilitating the classroom discussion when implementing photographs and CRSs?

RQ1.3. What are the interaction patterns of discourses between the students and the teacher when learning and teaching with photographs and CRSs?

Research Goal 2: To investigate the change in student conceptual understandings about the concepts of day-night and cause of seasons through the TJ+TEFA instruction.

It is important to investigate what were the student understandings about the concepts before they had the instruction and how they have been changed after they had the instruction because it tells us how the instruction affected the student mental models. For this research goal, the following questions were addressed:

RQ2.1. What are student misconceptions about the concepts of *day-night* and *cause of seasons?*

RQ2.2. What is the knowledge gain after the students had the intervention?

Research Goal 3: To investigate the student and teacher attitudes towards the TJ+TEFA instruction and to understand the pedagogical roles of photographs in this pedagogy.

Because this type of lesson was newly introduced to students and a teacher, one of my interests was to hear what they thought about learning and teaching with photographs and CRSs. In addition to their attitudes and thoughts about the lessons, how they saw the roles of photographs in the pedagogy was investigated.

RQ3.1. How do the students think about learning with photographs and CRSs in the TJ+TEFA instruction?

RQ3.2. How does the teacher think about teaching with photographs and CRSs in the TJ+TEFA instruction?

RQ3.3. What are the pedagogical roles of photographs in the TJ+TEFA instruction?

Methods

Setting and Participants

The setting of this study is astronomy classes at a middle school in the northeastern US. Mary who had the teaching experiences of middle school astronomy for more than 10 years was teaching five 6th grade astronomy classes in Fall 2008. Among her five classes, two classes were taught with the lessons that I had designed with the TJ+TEFA instruction (intervention classes). Three other classes were taught the same way that Mary had taught in previous years (traditional classes). I observed the two intervention classes and one traditional class. Each class size was 18~20 depending on class. The students in this school were mostly white. There were a few African Americans, and Asians were very rare. Seating charts of the two intervention classes are provided in Appendix D.

Data Collection

To answer for the research questions, various data were gathered: classroom observations with fieldnote-taking and video-recordings; student pre- and post-conception survey; student attitude survey; teacher interviews; and student works that were performed during class.

a. Classroom Observation with Fieldnote-taking and Videorecordings

   The two intervention classes and one traditional class were visited, observed, and videotaped every day when the topics of day-night and cause of seasons were covered during the period of Oct.7 - Nov.10, 2008. During the period, there were some days that the students went to field trips, participated in school fund-raising walks, teachers' workshop days, test days, or the teacher was absent due to her illness, etc. I took field notes while observing the classes and videotaped the classes. While students were working as groups, I picked one group that was having an interesting discussion. Although some students may have arisen to be more explicitly observed as my observation continued, my early stage of observation was focused on all the students in general regarding their interactions each other. While observing them in class, I tried to capture student misconceptions and procedures of the development of their reasoning and their interpretations of photographs.

b. Student Conception Survey (Appendix C-1)

Student conception survey was performed before the instruction (pre-test) and after the instruction (post-test) in both intervention and traditional classes. The survey was all open-ended, asking: definition of daytime and nighttime; reason for day-night cycle; length of daytime in different places on earth; length of daytime throughout the year; and reason for seasonal change.

This survey had two main goals in this research. One was to discover student ideas about the concepts of day-night and seasonal change. The other one was to diagnose whether or not there was a conceptual gain after the instruction by comparing pre-test and post-test results, and how it was different or similar between the intervention and the traditional groups. Students filled it out individually in the class without seeing any references or materials.

c. Student Attitude Survey (Appendix C-2)

This is to understand student attitudes towards the lessons in the intervention classes. This consists of open-ended and multiple-choice questions. This survey asks students about how they felt learning with photographs and CRSs and how they felt the classroom discussion. This survey was conducted after the curricular unit was ended. As a supplement, I frequently conducted a short survey at the end of a class, asking "*How did you feel about today's lesson? Was there anything that you liked, disliked, or surprised? What was it and why?*"

d. Teacher Interviews (Appendix C-3)

The interviews are to hear how the teacher thought the lessons went in the intervention classes. The teacher interviews were conducted before the curricular unit was started as a baseline data (pre); during the lessons went (mid); and after all the lessons were ended (post). The pre and post interview was conducted once for each, and the mid-interview was conducted 4 times. I had a standardized interview questionnaire (see Appendix C-3). Based on the interviews, I sometimes slightly revised the lessons on which she did not feel comfortable to teach or if there was anything that she thought to be needed to be modified. In addition, I was curious how she saw this discussion-oriented pedagogy and how she thought it affected her students' learning. By hearing from her, I was able to keep my insight of observing the class to be much objective and accurate. All the interviews were recorded and transcribed verbatim. In addition to those standardized interviews, I closely worked with the teacher to hear her voice, to revise the lessons, and to give her help with implementing this new pedagogy during, before, and after each class. This was performed informally and therefore was not recorded.

e. Student Works

Student group work products, worksheets, and writings were collected in the intervention classes as supplementary data.

Table 3 summarizes the data collection of this study that I have described above.

Table 3. Data Collection

Data	How often	Note	Research Questions
Classroom Observation & Videorecording	Every day during the unit	Videorecordings transcripts	Q1.1 Q1.2 Q1.3 Q2.1
Student Conception Survey	Pre-test Post-test	All open-ended Qs	Q2.1 Q2.2
Student Attitudes Survey	After completing the whole unit	Open-ended & Multiple-choice Qs	Q3.1 Q3.3
Student short survey	At the end of each class, infrequently (during the unit)	Student reflection in the class.	Q3.1 Q3.3
Teacher Interview	Pre-interview Mid-interview Post-interview	Audiorecordings transcripts	Q3.2 Q3.3
Student Works	During the classes	group works, worksheets, or any student writings	Q2.1 Q2.2

Analysis

As an exploratory study in an understudied area, analysis about discourses and student-teacher interaction focused mostly on coding of video episodes. The purpose of such an exploratory case study is to provide existence demonstrations of newly observed behavior patterns that promote the generation of hypotheses about effective teaching and learning strategies.

Data analysis began at my first observation of the class as it is the nature of the qualitative data analysis method (Corbin & Strauss, 2008). While I was observing the classes, rough categories and themes started to emerge. The videorecordings of the intervention classes were observed several times to recognize various modes of teaching such as whole classroom discussion (WCD), small group discussion (SGD), small group work activity, or teacher lecture, etc. All the whole classroom discussion, small group discussion, and group work activities of the two intervention classes were transcribed verbatim, using the software *InqScribe* and *Transana*. The parts about which the teacher was giving long lectures or demonstrations, checking student homework, or that the students were working individually (such as writing) were not included in the transcription because they were not the main interest of this study. The video segments that were transcribed and their class modes are listed in Appendix E.

The video transcriptions were analyzed following a *grounded theory approach* (Corbin & Strauss, 2008; Strauss & Corbin, 1990), originally known as constant comparison techniques, performing open coding, axial coding, and theory generation. This method was used to differentiate and refine new constructs describing student and teacher discourses and student-teacher interaction. First, student and teacher discourses were coded as the first step of *conceptualizing*. Second, those *codes* were *categorized* into sets of similar concepts by making connections between them. As the procedures of the first and the second steps were repeated and the data were revisited, the codes and the categories were revised and became more sophisticated, and eventually fixed codes were developed. Developing a theoretical model involved an interpretive analysis cycle of segmenting the video data; making observations from each segment; formulating an interaction pattern that can describe and to some extent explain the observation; returning to the data to look for more observation in the same pattern; and criticizing and modifying it. Based on those procedures, a theoretical model was finally developed to explain the interaction between the students and the teacher. Throughout the analysis procedures, the software *NVivo* was used. The frequency of coding schemes and the theoretical model of interaction patterns are displayed as a certain form such as tables and diagrams to help understanding the meanings of the data (Miles & Huberman, 1994).

The conception survey consists of seven open-ended questions asking to describe or to draw to explain scientific phenomena. Among the seven questions, six questions were used for analysis. The last question was redundant and many students did not fill in their answers for it. Therefore, I decided not to include the last question for analysis. Student responses to the conception survey were read through and categorized to find common misconceptions among the students. The misconceptions found from the survey are listed with their quotes in the Findings.

Rubrics were developed for each conception survey question, and student responses to it were scored based on the rubrics to investigate their knowledge gain. For blind review, student names and class numbers were covered with papers during the process of scoring. By comparing pre- and post-test results for each student for each class, student knowledge gain was measured. The result is presented descriptively using tables and a graph. To check if there was a significant gain for each class, a hypothetical test was performed using repeated-measures t-test. To understand the efficacy of the TJ+TEFA lessons, the student knowledge gains were compared between the intervention group and the traditional group using independent samples t-test.

Reliability of the analysis with the rubrics was tested by a volunteer who was a doctoral candidate in astronomy. He randomly chose 12 students, 3 students each from 4 different survey sets (two from pre-test and two from post-test), and scored their responses with the rubrics that I provided. Because 6 questions of the conception survey were used for analysis, he looked through student responses for totally 72 questions (12 students x 6 questions). Among them, only two questions that he scored were slightly different from what I had scored. It is a pretty much good agreement, and it can be said that the analysis of the survey with the rubrics is reliable.

The attitudes survey consists of both open-ended and likert-type questions. The likert-type questions were asked students about their learning experiences with the new lessons to choose among the choices; strongly no, no, I don't know, yes, and strongly yes. The number of students who chose for each choice was counted, and it is provided with a table in the Findings. Some of the likert-type questions were grouped into several categories that had similar themes. Their Cronbach's alpha values are provided to present the reliability of the internal items. The number of students for each category was averaged, and its mean values for each category are presented in the Findings.

Open-ended responses of the attitudes survey and short surveys were categorized into several groups that had similar themes. The recordings of the teacher interviews were transcribed verbatim and analyzed following the grounded theory approach, categorizing several groups based on similar themes. The student open-ended data and the teacher interview data provided deeper understandings about their attitudes toward learning and teaching the lessons with the photographs and the CRS technology.

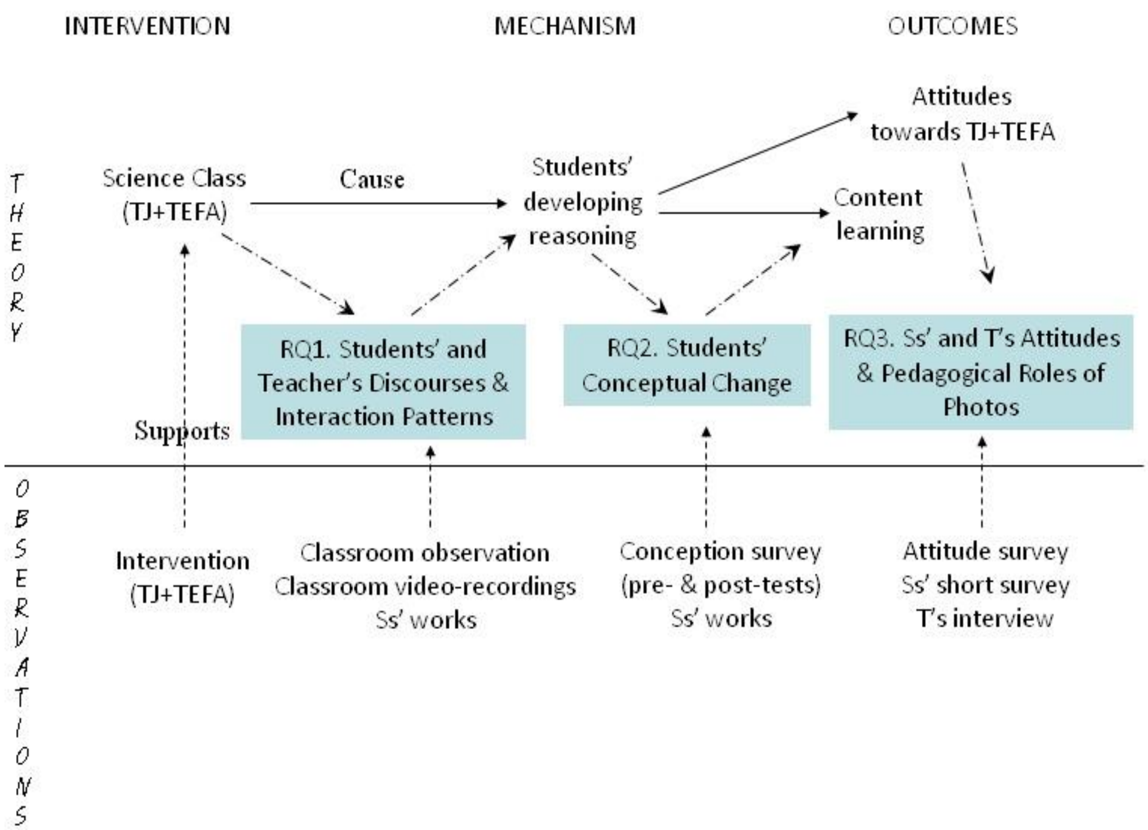


Figure 8: Structure of the analysis of this study

Figure 8 shows the structure of the analysis in this study. It shows how each data was used to answer for the research questions. There was an intervention of TJ+TEFA instruction, and various data were collected. The intervention and the data are visible to us, in other words, they are *observable.* Students in the intervention group developed their reasoning, and the classroom was observed and videotaped and the students' written works were gathered. These data were analyzed to understand various types of discourses and their interaction patterns that the students and the teacher shared while participating in classroom discussion. As the result of the *mechanism*, learning with the new instruction, two *outcomes* were produced. One is student content learning, and the other is student and teacher attitudes about the lessons. The student content learning, the research question 2, was investigated by the conception survey (pre- and post-tests). The student and teacher attitudes toward the lessons, the research question 3, were investigated by analyzing attitude survey, short survey, and the teacher interviews. The attitude survey, shorty survey and the teacher interview data provided understanding about the pedagogical roles of photographs in the lessons.

CHAPTER 4

FINDINGS

In this chapter, I describe findings of the study: student and teacher discourse types and interaction patterns in classroom discussion; student misconceptions and pre- and post-conception tests results; and students and teacher attitudes toward the lessons.

First, I describe various discourses that the students and the teacher shared in classroom discussion during the lessons of implementing photographs and CRSs. Studies have identified student and teacher discourses and their interactions in science class (e.g., Chin, 2006; Hogan, Nastasi, & Pressley, 2000; Roth, 1996; van Zee & Minstrell, 1997a, 1997b; van Zee, Iwasyk, Kurose, Simpson & Wild, 2001), but little has known how students interact with a teacher in a specific context in which photographs and CRS technology are implemented. One of the goals of the study is to investigate types of discourses when students learn with photographs and CRSs, and to find a student-teacher interaction model that possibly suggests an efficient pedagogy to use photographs and CRSs in science class. Therefore, after I introduce student and teacher discourses identified from the data, I will provide episodes that describe student-teacher interaction patterns.

Second, I describe misconceptions that the students showed in the conception surveys for the concepts of day-night and seasonal change. Some of the misconceptions are similar to the ones that have been reported in previous literature (see Chapter 2). But, this study also reveals various misconceptions that have not been reported but that are commonly and strongly held among the students.

Third, after I describe misconceptions, I provide rubrics that I used to measure the student performances on the pre- and post-conception surveys. The student pre- and post-test scores will be reported for each class. At the end of the section, I provide statistical test results that measured the student knowledge gains between pre- and post-test and between the intervention and the traditional groups.

Fourth, I report students and teacher attitudes toward the lessons that were investigated by the student perception survey, the short surveys, and the teacher interviews. That provides the information about how the students thought about the lessons, the photographs, and using CRSs while they were learning the astronomy concepts. The results of the teacher interviews revealed the difficulties that the teacher encountered while she was teaching the lessons and her thoughts about implementing photographs and CRSs. At the end of every subchapter, I summarize the findings of that section.

1. Discourse and Interaction Patterns

In the intervention classes, there were various types of teaching modes including whole classroom discussion with photographs with/without CRSs; small group discussion with photographs and student worksheets; small group discussion with hands-on activity (globes and light bulbs); small group presentation; and teacher demonstration. During the discussions, students and the teacher used various types of discourse. Here I present coding schemes that were identified in student and teacher discourses mainly when photographs and CRSs were used in whole classroom discussion and small group discussion.

Coding Schemes

In this section, I describe three different themes of codings found in the study: student discourse that represents visual thinking; student discourse that represents reasoning status; and teacher discourse that facilitates classroom discussion with the implementation of photographs and CRSs.

Student Visual Thinking Discourse

I identified several categories of discourse that the students used while they were participating in the discussion when learning with photographs and CRSs: *direct description, visual reasoning, visual spatial thinking, dynamic direct description, dynamic visual reasoning, dynamic visual spatial thinking, applying a scientific concept, connecting to experience*, and *imagination*.

Direct Description (DD) Students simply describe what they see in a photograph. When students engage in this discourse, they present the information that they actively explore and perceive with their vision from a photograph or any visual material. This may be also called as *visual perception*.


(photo10)

T: What do you see in this photo?	
S: An igloo.	*[DD]*
T: An igloo. What else do you notice?	
S1: Polar bear.	*[DD]*
S17: A lot of ice.	*[DD]*
S11: Some really bright light inside like the three little igloos.	*[DD]*
S6: Um, the light in the igloo is as bright as the sun.	*[DD]*

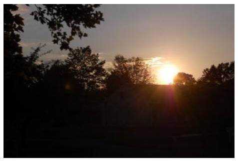
Visual Reasoning (VR) Students draw a conclusion or show a process of thinking from what is seen with their vision in a photograph or any visual material. This definition of visual reasoning may be a rather narrow meaning. Students reason within the same spatial frame of reference that a photograph or a visual material provides. In other words, students who engage in this discourse create an image in their mind's eye in the same spatial frame of reference as their vision detects the visual representations. So, their vision and the image created in their mind's eye stay in the same spatial frame of reference. For example, in the below quote, the student's point of view stays on earth as provided in the photograph. The next category, *visual spatial thinking,* is somewhat different from this.

(photo 1b)

S11: I think it's about noon because you can see the field and whatever is under it, and you can see some trees around it, and just it looks like higher up in the sky, *[VR]*

Visual Spatial Thinking (VST) Visual spatial thinking discourse is when students are able to change or to add a spatial frame of reference and to form or to transform an image in their mind's eye. In other words, students who engage in this discourse are able to see an image in their mind's eye that is not provided in a photograph or in a visual material. In the below example of this discourse, the student's point of view is taken from space (out of the earth), which is not presented in the photograph.

photo a photo b




(photo 1a) (photo 1b)

S6: Well, I think, in photo b, showing more sunlight than photo a, cause [in photo a] some of the sun is still on the other side of the earth, so you still, you can't see some of the sun. *[VST]*

Dynamic Direct Description (DyDD); Dynamic Visual Reasoning (DyVR); Dynamic Visual Spatial Thinking (DyVST) Dynamic direct description is when students describe what they see with their vision in a photograph as moving. Dynamic visual reasoning is when students draw a conclusion or show a process of thinking from what is seen with their vision in a photograph or any visual material by imagining it as moving. Dynamic visual spatial thinking discourse is when students are able to change or to add a spatial frame of reference and to form or to transform a dynamic image in their mind's eye. If direct description, visual reasoning, and visual spatial thinking imply static image, dynamic direct description, dynamic visual reasoning, and dynamic visual spatial thinking imply moving and active image.

(photo 13)

T: What do you notice in this photo?

S2: The sun looks like setting. *[DyDD]*

T: Okay, anything else?

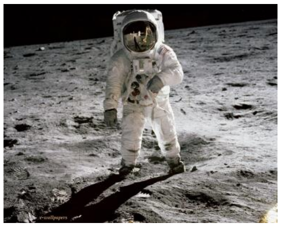
S6: There is more and more of water. … *[DD]*

T: Okay, majority are thinking dawn or sunset, a couple think noon midnight, it, any of the above or it depends. Okay, um most people chose c. Why do you think so? …

S3: I chose c um because it looks like the sun is either coming up or it's going down because the other part of the water it's dark and like right in the middle it looks like light. *[DyVR]*

T: Okay.

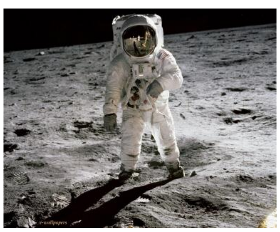
S14: I chose c because if you look you can see the reflection of the sun on the water. *[VR]*



(photo 3)

S13: Probably what he means is at night the sun goes behind the moon and makes the moon um like really bright and since the shadow is going um not forward to the side it looks like the sun is going down, behind the moon. *[DyVST]*

Applying a Scientific Concept (ASC) Students apply a scientific concept, mention scientific words/terminologies or a mathematical formula, or perform a mathematical calculation in their reasoning, either perfectly or partly logical, or either in a proper or in an improper way.



(photo 3)

S14: Yep and um, the sky looks black. *[DD]* Without having the light you have the sun because of the earth's atmosphere. Um, I don't know how to explain it but the earth's atmosphere makes it look so its bright out. *[ASC]*

T: On earth?

S14: Yeah (nodding), and then on the moon, it really doesn't have atmosphere. *[ASC]*

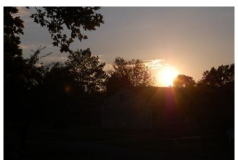
Connecting to Experience (CE) Students bring their own experiences to the discussion. In this category of discourse, students often use the word such as "usually", "sometimes", or "when I …", etc.

(photo 11)

S7: Um I saw this on Animal Planet, um they have like eggs (inaudible), and usually when they have the eggs it's usually winter time. *[CE]*

Imagination (Im) This category might belong to a type of visual reasoning. However, this category is distinguished from VR because the discourse does not require considering a spatial frame of reference in student reasoning. In other words, students *imagine* what they cannot see with their vision.

photo a



(photo 1a)

photo b

(photo 1b)

S15: they might have thought it would <u>be windy</u>, in photo b, *[Im]*

…

S10: in picture b, it would <u>be humid</u> also. *[Im]*

<u>Student Reasoning Status Discourse</u>

These discourses indicate student reasoning status: *claim*, *misconception*, *questioning*, *confusion*, and *change*. *Claim* is a student statement that is considered to be compatible with the teacher's target concepts in their reasoning. *Misconception* is a student understanding of a concept in the way that is not currently accepted in science. *Questioning* is a student discourse that points out other student claims in a doubtful way or that they bring their own questions in classroom discussion. *Change* is a student statement that they want to change their responses or opinions to a different one after hearing other students' thinking. *Confusion* is the indication of students' confusion in their reasoning.

S8: D has like a longer day than B. *[claim]*

But I don't know if it has a longer day than C. It's really confusing. *[confusion]*

S14: Well I said C but I want to change mine to D because S6 made …. *[change]*

S: So if the earth is spinning that way, and you go that way on a plane, you're going back in time? *[questioning]*

S7: Um, I chose C because the um I felt there was no daytime on the moon. *[misconception]*

Teacher Discourse

There are mainly nine types of teacher discourse that Mary used in the discussion when teaching with photographs and CRSs: *requesting preliminary observation, provocative concept development question, reading off a histogram result, revealing an answer, reasoning question, spontaneous guidance question, teacher clarification, encouraging students' participation, and formative assessment meta-level communication.*

Requesting Preliminary Observation (Obs) Teacher requests students to observe photographs or any visual material by asking a question such as, "What do you see in the photograph?"

Provocative Concept Development Question (CDQ) This category includes *CRS questions* and *prepared teacher's questions*. CRS questions (CRS Q) are mostly planned and prepared ahead of the lessons and are the major framework of leading the lessons. These were provided to the teacher as the part of the prepared curriculum unit. CRS questions also can be created and asked by a teacher on the fly when she thinks that is necessary during class. *Prepared teacher's questions (T_preparedQ)* are planned and prepared ahead of the lessons, but are not asked with CRSs. Those questions are asked by a teacher orally during classroom discussion, and they play a role of directing key discussion points. The curriculum unit also included this type of questions.

Reading off a Histogram Result (H) This discourse is the one that the teacher uses after looking at the histogram result that the CRS gathers from student responses. The teacher might say, "ok, the majority chose c." or "we have 16 people chose a."

Revealing an Answer for the question (A) Teacher reveals a correct answer for a provocative concept development question: "The actual answer, okay, well it could be anytime of the day." This discourse usually occurs at the end of the discussion, but it can also be occured in the middle of the discussion depending on the teacher's purpose.

Reasoning Question (RQ) The teacher asks students *why* or *what* questions to help them develop reasoning: "Why do you think so?", "Why do you say that?", "Why do you think so many people chose c?", "What are you thinking about it here?", "What do you mean by that?", "What do you think?", "What would explain…?", "Why not?", and etc.

Spontaneous Guidance Question (guideQ) This is a discourse when a teacher brings to the discussion on the fly to guide and help students to develop their conceptual understanding. If reasoning questions (RQ) are more like why-type questions, expecting to hear open responses, spontaneous guidance questions are asked to students with expecting to hear more concrete answers: such as, "What about…?", "How would it be …?", "Where do you think…?", "What's the difference between …?", "Ok, give me an example.", and etc.

Teacher Clarification (Tclarif) Teacher summarizes what students have said during classroom discussion, such as, "what I'm hearing so far is …", or clarifies a concept at the end or during classroom discussion. Small lectures or reviews by the teacher also belong to this category.

Encouraging student participation in discussion (Disc) There are mainly three types of discourse that the teacher used to encourage students to participate in discussions. The first type, *adding*, is when the teacher asks students to add something ("anyone else have something to add?"), seeks someone to say ("anybody else?"), or asks other students to speak their opinions about what a previous student just have said ("what do you think about what he just said?"). The second type, *repeating*, is when the teacher simply repeats what students just have said, or asks students to confirm if she (the teacher) understood it correctly what they just have said ("… is that what you said?"). The last type, *passing*, is when the teacher gives other students chances to answer or to speak their opinion for a question that a student has asked. As such an example,

S: If it were midnight, wouldn't it be darker?	*[questioning]*
T: If it were midnight, wouldn't it be darker?	*[Disc.repeating]*
Anyone wants to respond to that?	*[Disc.passing]*

Much of the discourse in this category may be the *reflective toss* (van Zee and Minstrell, 1997a), in which a teacher catches the meaning of a student's statement and tosses the responsibility to answer back to the student or to the whole class.

Formative Assessment Meta-level Communication (FAMC) This is the discourse that the teacher uses to build trust between her and her students about formative assessment and their participation in discussion. This discourse may help students to adapt to the new pedagogy and to feel comfortable to speak out their opinions. Below are some quotes from the teacher in this category.

> T: Okay, okay. And you don't, people don't have to be right or wrong, what we're doing is we're trying to talk about this so it will help us figure things out.

T: ok, you did a great job for participating.

T: Okay. Now, what you all are telling me here is great. Whether it's good to get all that out because we normally don't get to talk about this type of thing when you are in your regular lesson what you get and what you don't get. And if we look a lot of people just weren't quite sure but listening to each other kind of coming up with some more understanding than we had before.

T: But, we will um, we will be learning about this after. And you know I have to tell you, this is confusing even for adults. Really.

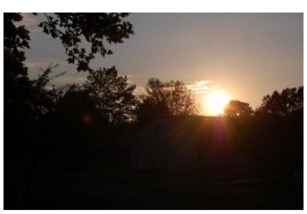
T: And it's okay if you're not sure still because we'll be talking about this more later.

Student-Teacher Interaction Patterns

In the previous section, I presented different types of student-teacher discourses that occurred in classroom discussion during the lessons in which photographs and CRSs were used. Now I describe interaction patterns that the students and the teacher shared during the discussion. Depending on teaching modes, there are three primary types of student-teacher interaction patterns: 1) when only a photograph is used without providing a concept development question, 2) when a concept development question is used with a photograph, but its answer is not revealed until the end of the discussion, and 3) when the answer of the concept development question is revealed during classroom discussion.

Interaction Pattern 1

The below episodes are from the first day of the curriculum unit. In this class, the teacher showed students two photographs and had the below conversation:


(photo1a)

Intervention class 1

T: What can you tell us about the photo, S5? *[Obs]*

S5: The sun's going down. *[DyDD]*

T: Okay, why do you say that the sun's going down? *[RQ]*

S5: Because the sun is like higher in the sky and you can see the lights on the trees. *[VR]*

Intervention class 2

T: I'm going to show you some photos. Okay, let's take a look at this first photo here. Okay. I want you to look at it carefully. (pause) S21, what do you notice about it? *[Obs]*

S21: Um, it's rising or setting. *[DyDD]*

T: It's either sun rising or setting? *[Disc.repeat]* Okay. Anyone else? *[Disc.add]*

S35: I think the sun is rising, cause, um, how it's all dark around the sun, except like it looks like it's coming up. When the sun's setting, it wouldn't be that bright. *[DyVR]*


(photo1b)

Intervention class 1

T: Ok, let's take a look at picture two. What do you notice about this photo? *[Obs]*

S13: Well, it's (inaudible)

T: Ok, why do you say that? *[RQ]*

S13: Because the sun is right up in the sky and (running/not clear) little bright, clouds. *[VR]*

<u>Intervention class 2</u>

T: Okay. Let's look at the next one. Let's look at the photo. S30, what do you notice? *[Obs]*

S30: It's like in the middle of day. *[VR]*

T: Why do you think that? *[RQ]*

S30: Cause it is in the middle of the sky [inaudible] *[VR]*

T: Okay. S28?

S28: [inaudible] Cause it's like in the middle, it's like twelve o'clock, maybe. *[VR]*

As can be seen in the episodes, the teacher started with a preliminary observation question (Obs) asking the students to observe the photographs. The most common discourse type to which students responded was describing what they saw from the photograph, direct description (DD). Some students described it as a moving image (DyDD) and some others responded with visual reasoning (VR) to the teacher's preliminary observation question (Table 4).

Table 4. Number of codings for each student discourse type to the teacher's preliminary observation question (Obs) discourse

Teacher discourse	Obs ↓	Intervention class 1	Intervention class 2	total
Student discourse	DD	7	9	16
	DyDD	2	3	5
	VR	2	4	6

After listening to the student descriptions, the teacher used reasoning questions (RQ) to ask for students to represent what their thinking was while they were looking at the photographs (VR or DyVR) (Figure 9). This may be the most fundamental interaction pattern between the students and the teacher during the classroom discussion in which the photographs were used. This interaction pattern occurred 19 times (10 cases at the intervention class 1, and 9 cases at the intervention class 2).

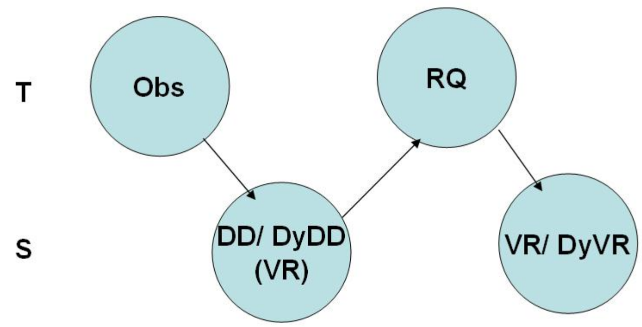
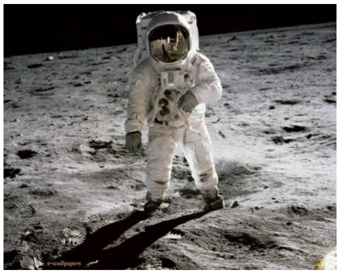


Figure 9: Interaction Pattern 1: Obs→DD/DyDD/(VR)→RQ→VR/DyVR

<u>Interaction Pattern 2</u>

The second type of interaction pattern often follows after the first interaction pattern, and occurs when a concept development question (CDQ) is used. The main concept development questions that were used in this study are the form of CRS questions (CRSQ). The teacher sometimes did not use the CRS technology and asked a concept development question orally (preparedQ), depending on her convenience or class time when there was not enough time to use the CRS. She also cast questions spontaneously (guideQ) to promote students develop their reasoning during classroom discussion. CRSQs were often used in the beginning to start up the discussion.

The below episodes were occurred on the third day of the unit. In this lesson, the teacher showed a photograph of an astronaut on the moon and asked students a CRS question.



(photo3)

CRS Q. Is it day or night on the moon where you stand at the moment the photo is taken?

a) Day
b) Night
c) It depends.

Intervention class 1

T: So now let's take a look at this photo right here. You have to decide, is it day or night on the moon where they are standing at the moment the photo is taken, same photo. Think for a minute. Does it look to you like it's day, night, or does it depend on something? Think about that for a minute and then I'm going to ask you to use your clickers to tell me your response. *[CRSQ]*

(Students vote with their clickers.)

T: We have a lot of, it depends, and then we have some people who aren't sure if it's either one or the other. … *[Histogram]*
But why was why do you suppose some people chose A? What if you chose A? S13, what do you think? *[RQ]*

S13: Because, um it looks like there's a light shining on the moon and um, you can see a shadow so it would look like. *[VR]*

T: Okay, so because the light here and the shadow? *[Disc.repeat]* Okay, anyone else want to say something about choice A? S6? *[Disc.add]*

...

S6: No, um, after thinking about it, when you were still (mumbling) because it looks like it's still bright and it' not dark on the surface of the moon and there's still a shadow of the person, a long shadow, cause it's a reflection and it might be (sun) rising or setting. *[ASC/ DyVR]*

T: Okay, S5, what would you like to say?

S5: Well, um, I'll be honest, I think B because I looked at the sky and I didn't, like, I don't know, I thought it was B because like it was really dark in the sky *[VR]*
and usually (inaudible), even though the moon is still there when it's daylight hour I still saw it was *[CE]*, you know, …

…

Intervention class 2

T: Okay. Take a look at the next photo here, same photo, this time I want you to try and think. If you think it's day or night where you stand at the moment the photo is taken, the choices are day or night. *[CRS Q]*

(Students vote with their clickers.).

T: Okay. Interesting histogram here. People said every choice here. I want you to think about why you made the choice you did, … Choice A, we had two people say daytime. *[Histogram]*
Anyone like to share why they made that choice. S27? *[RQ]*

S27: Well I chose A because, I forget where but I learned somewhere that when astronauts outfit has a reflection, and if the sun is out, that's what the helmet is made for. *[CE]*

T: So that's why you chose it. Anyone else wanna speak about that? S26? *[Disc.add]*
…

S26: If you were seeing this way [turning], on the left on the ground looks bright *[DD],*
so the sun would be coming from that way. *[VST]*

T: So it's lit up. Somebody had their hand raised up here? S38?

S38: I thought that if the moon was kind of lit up, then it would be daytime or something. *[VR]*

T: Okay. S24?

S24: Most of where he's standing is maybe where the sun would be daytime. *[VR]*

T: Okay. Because of where it's lit you said? It's bright in the background there? *[Disc.repeat]*
Anything else you see in that photo that might make you think it might be day? S31? *[Disc.add]*

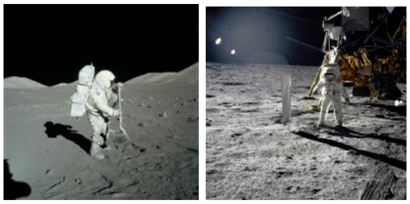
S31: The shadow.

T: Ok shadow right here in the foreground?

S31: Yes.
…

The below episode was occurred on the fifth day of the unit at the intervention class 1.

A. B.



(photo 5)

CRS Q. Which photograph do you think was taken at nearer noon of the moon day?

a) Photo A
b) Photo B
c) Photo A and Photo B were taken at same time of the moon day.
d) It doesn't have enough information.
e) I don't know.

<u>Intervention class 1</u>

T: Which photograph do you think was taken nearer noon of the moon day? *[CRSQ]* (Students vote with wither clickers.)

T: Many people chose A. *[Histogram]* Who chose A? S6, Why did you choose A? *[RQ]*

S6: I chose A because in photo A it's not very long shadow and in photo B there is a long shadow, so the sun would've been closer to the horizon which would be longer, and the sun was right above your shadow. *[VST]*
…

Table 5. Number of codings for each student discourse right after following to the teacher discourse, CRSQ→H→RQ

Teacher discourse	CRSQ → Histogram → RQ ↓	Intervention class 1	Intervention class 2	total
Student discourse	VR	8	7	15
	DyVR	2	2	4
	DD	3	0	3
	CE	1	4	5
	VST	1	0	1
	ASC	1	1	2

As can be seen in the episodes, there is a pattern when the teacher used with CRS questions. The teacher poses a CRS question (CRSQ), and the students answer using clickers. When their responses are shown with a histogram, the teacher reads it off (H) and asks students to present *why* they chose it (RQ). Then, students respond through various discourse types.

Table 5 shows the number of codings of each student discourse type in this interaction pattern. As can be seen, the most common student initial response to the teacher's CRSQ→ H→RQ discourse was visual reasoning (VR). Figure 10 represents this pattern as a diagram. The teacher initiates a concept development question, mostly with CRSQs in this study, and students answer for it. Histogram result is shown (H) and the teacher asks students a reasoning question (RQ). The most common student discourse to RQ is visual reasoning (VR), although there are other types of discourse such as VST, CE, DD, ASC. Then, the teacher continues the discussion by encouraging students to participate in (Disc). During the discussion, the teacher does not reveal what the answer is.

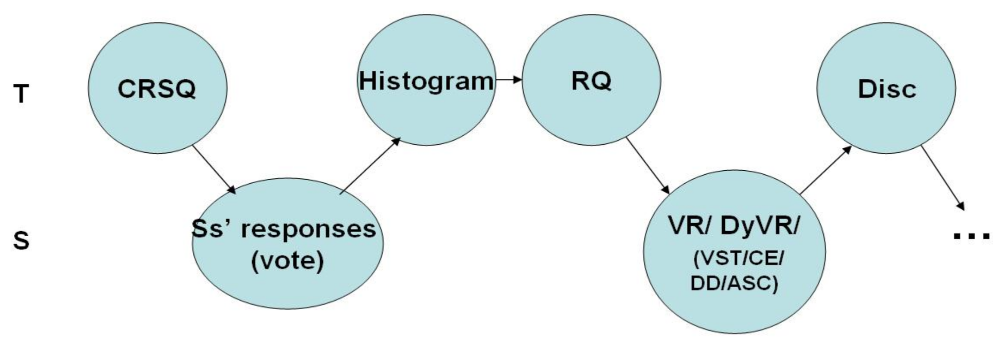


Figure 10: Interaction Pattern 2: CRSQ→(Ss' responses) →H→RQ→VR/DyVR→Disc

Interaction Pattern 3

The third interaction pattern is similar to the second interaction pattern. The difference is that the teacher reveals an answer in the middle of the discussion, and continues the discussion based on it. In this pattern, the concept development question (CDQ) acts as a discrepant question (Rea-Ramirez, Nunez-Oviedo & Clement, 2009), which aims for students to see a contradiction in their belief.

The below episodes were performed on the day 8 of the unit at the intervention class 1, and on the day 7 at the intervention class 2. It was the beginning of introducing a new concept, *polar darkness* and *midnight sun*. In this lesson, the teacher showed students a photograph of penguins and gave them a CRS question.


(photo11)

CRS Q. This photo was taken in South Pole in June. When do you think it was?

a) At Noon

b) At Midnight

c) At Dawn or Sunset

<u>Intervention class 1</u>

T: ... What happens, this was taken in the South Pole, it was taken in June. What you need to decide is when you think it was taken. At noon, at midnight, at dawn or at sunset. … Send your answers. *[CRSQ]*

(Students vote with their clickers.)

T: Okay and we have everybody's response. Okay, so this is the histogram. *[Histogram]* Noon time. S2, do you think it could possibly be noon in this photo?... Can you tell us why? *[RQ]*

S2: Um, Maybe the sun is not bright like in the other pictures. *[DD]*
…

T: Okay, quite a few people thought midnight. *[Histogram]* Why do you think most people thought midnight? S9? *[RQ]*

S9: Maybe because it's so dark out. *[VR]*

T: So dark out. *[Disc.repeat]* Okay. S18, anything else? *[Disc.add]*
…

S14: It could be in a cave. *[VR/ Im]*
…

S5: I think C and um I thought it might have been dawn or at sunset because getting dark doesn't mean it looks like midnight and um for the noon part I wouldn't think they could say that, it doesn't really look like noon cause it's really dark out, even though it's a cloudy day still it's not that dark. *[VR/ CE]*
…

T: Okay. Anyone else wants to talk about their choice or any of the other choices? *[Disc.add]*

S: What is the actual answer?

T: The actual answer, okay, well it could be anytime of the day, the sun comes out, but it happens this was actually noontime at into at the South Pole. ***[Answer]***

T: Now what would explain how it could possibly be noon time? S6? *[RQ]*

S6: It could be the polar darkness or a (inaudible) *[claim]*

T: Okay it could be polar darkness and that's the actual reason right now. ***[Answer]*** Why do you think polar darkness happens though? What would make it happen? S14, what do you think? *[RQ]*

S14: Well um, it would probably happen because polar darkness has to be in both south pole and in north pole *[claim]*

T: Why? *[RQ]*

S14: On the North Pole, there's somewhere, center in north pole, you can't see the sun as much. *[ASC]*

T: Why not? *[RQ]*

S14: Because some of the earth is blocking it. *[ASC]*

T: Some of the earth is blocking the sunlight? *[Disc.repeat]*

S14: (Inaudible) horizon (inaudible).

T: Okay, Why? *[RQ]* Any ideas why? S1. *[Disc.add]*

S1: Um because some parts, some parts of the year, the earth is on a tilt on its axis and the sun can't and when it's on a tilt, the sun can only come up to a certain point and it might not be able to return to the other side, when the axis is on a tilt. *[ASC/ VST]*

T: Okay. S6?

S6: Um because when say you're in Massachusetts, it would go from one side of the earth to the other one earth rotates. But when you're in the South Pole you um, you just stay in that place, even though the earth is rotating and the sun would stay in the same place. *[ASC/ DyVST]*

T: Okay, we're talking about two extreme points on earth, North and South Pole. S7?

S7: Um I saw this on Animal Planet, um they have like eggs (inaudible), and usually when they have the eggs it's usually winter time. *[CE]*

T: So, it must be one of those times. S11?

S11: I was watching Animal Planet too, and they have this show I don't know what it was called, but it was like this whole show on Penguins, and it showed like how the eggs would be born, and that they couldn't drop it on the ice or else the egg would immediately freeze, so they always had to keep it like under their feet to stay warm. And even if they dropped it for like a second, the egg would be dead. *[CE]*

T: Happy feet. Okay. Okay I'm going to show you another photo now. So, um polar darkness where it does happen in both poles. Okay? Both December it would be in the North Pole area, um in the South Pole it starts in June. *[clarification]*

<u>Intervention class 2</u>

T: Okay. It was taken at the south pole during June. The last one was taken in December in the North pole, and this was taken in the South pole in June. So, again, we are gonna try to figure it out when do you think it was taken. Noon, midnight, or at dawn. Send your response. *[CRS Q]*

(Students vote with clickers.)

T: Ok, so, we have a few for each response. *[Histogram]* Anyone talk about why they chose noontime? (pause) midnight? S36, why midnight? *[RQ]*

S36: I chose midnight because it was darker than at dawn or at sunset. *[VR]*

T: Ok, it's darker than dawn or sunset. S37? *[Disc.repeat]*

S37: Because it is dark, it could be midnight (inaudible) *[VR]*

T: Ok, you think that they are sleeping at midnight? But, you are not (inaudible), Okay. Ok, S24?

S24: I think it could be noon because it is kind of layout (unclear), and you are still seeing it, if it is midnight it would be like a lot darker. *[VR]*

…

T: Okay. Anybody else want to talk about their choice or any other choice based on up here? S27? *[Disc.add]*

S27: I chose c because at the north pole picture that was like noon, so I thought it was sunset there and I thought just like (inaudible), so same at the south pole so it would be dawn or sunset and it's like just really dark because like right now for dawn or sunset is like being 7 o'clock now it's dark out for us. *[VR]*

T: Okay. So could it possible be daytime on this? Sort of? *[guideQ]*

(some Ss: yeah)

T: It could? Why do you say that S22? *[RQ]*

S22: Because like you said polar, polar (pause) happens on north pole and south pole and so on, they have polar night?

T: Okay. Polar darkness?

S22: yeah. That could be any of the above.

T: Ok, he said that it could be any of the three. How many agree with him?

S37: But, I thought it is from December to March for polar darkness. *[questioning]*

T: It does some places, (pause) in the north pole. This is south pole.

S27: This is the polar darkness in the arctic circle? *[questioning]*

T: So, this is south pole, we were just talking about polar darkness in the arctic circle. But there is also polar darkness in the south pole, too. So, this photo was actually taken at noon in the south pole. It could have been any of those times, though. Ours are not look like that. This is in the south pole, it is very dark and it is polar darkness again. ***[Answer]***

T: Why do you think it happens? It happens in the north pole and happens in the south pole. Any ideas? How about if you use the back of this paper and try draw a little picture. It would help what is your thinking. Why happens polar darkness?*[RQ]*
…
S33: (inaudible)

T: Okay. She said because the earth rotates, as it is rotating while revolving around the sun, the sun shines on parts of the earth that does not always reach the north and south poles. Okay. S31? *[Disc.repeat]*

S31: I think the equator, which is in the middle of the earth, gets most direct sunlight and then the north and the south pole is opposite, they get least direct sunlight? *[ASC]*

T: Okay, similar to what S33 was saying. S34?

S34: Maybe the south pole when the earth rotates how I called (inaudible), so maybe south pole where it is when the earth maybe gets least sunlight when the sun is facing the earth. (unclear) *[ASC/ VST]*

T: When the earth is facing the sun? Okay. So similar to what they were saying that the sun doesn't reach the parts of the north and the south poles even during the daytime? *[Disc.repeat]*

S34: Yeah.

T: Okay, S24?

S24: I think that because the earth is rotating [gesture] and the north and the south pole when it rotates the sun is not directly on two poles, [gesture] like not shining on two poles directly, so they don't get same amount of sunlight. *[ASC/ DyVST]*

Figure 11 represents the diagram of the third type of interaction pattern. In addition to the second interaction pattern, there is a discourse of the teacher’s revealing answer (A) during the discussion. Based on the revealed correct answer, the teacher askes the students to reason *why* the phenomenon happens (RQ), and continue to encourage the students to participate in discussion (Disc).

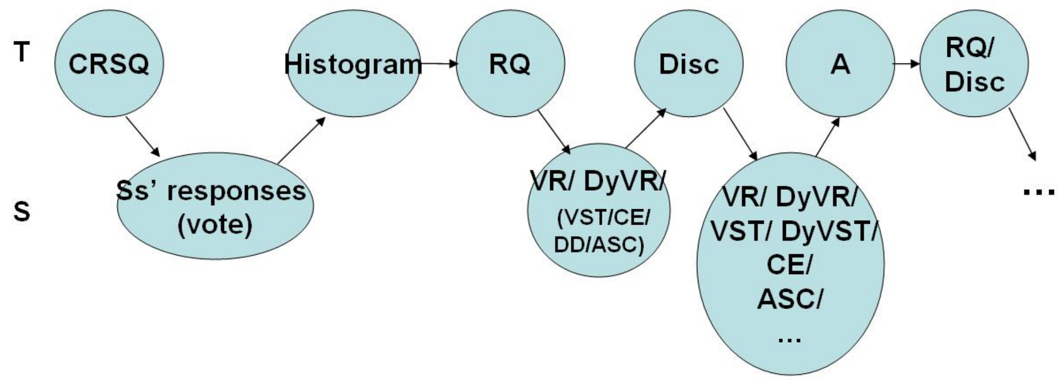


Figure 11: Interaction Pattern 3:
CRSQ→(Ss'responses)→H→RQ→VR/DyVR→Disc→…→A→RQ/Disc→...

Frequency of Discourse

Table 6 summarizes the number of codings for each discourse that occurred during the whole curriculum unit at both intervention classes. As can be seen in the table, the teacher used a lot of *Disc.repeat* and *Disc.add* discourse to encourage students to participate in discussion. She often repeated what a previous student said (*Disc.repeat*) and asked, "Anyone else?" *(Disc.add)*. In addition, she used a lot of *guideQ* and *ReasoningQ* in the classroom discussion to help her students develop their reasoning. The most common student visual thinking discourse is *Visual Reasoning (VR)*. The next most frequent one is *Applying a Scientific Concept (ASC)* and *Direct Description (DD)*. The number of *Visual Spatial Thinking (VST)* discourses was also high. While DD and VR were often observed in the earlier stage of the discussion, ASC and VST were often observed in the later stage of the discussion as the students developed more sophisticated reasoning as the discussion went on.

Table 6. Number of codings for each discourse during the whole lessons

T/S	Discourse type	Intervention class 1	Intervention class 2	Total
Teacher Discourse	Obs	16	18	34
	CDQ.CRSQ	24	21	45
	CDQ.preparedQ	14	13	27
	Histogram	41	49	90
	ReasoningQ	76	64	140
	guideQ	94	122	216
	Disc.add	81	74	155
	Disc.pass	4	4	8
	Disc.repeat	128	134	262
	FAMC	14	11	25
	Answer	12	20	32
	Clarification	27	35	62
Student Visual Thinking Discourse	DD	70	81	151
	DyDD	5	3	8
	VR	142	150	292
	DyVR	35	15	50
	VST	31	42	73
	DyVST	8	5	13
	CE	42	27	69
	ASC	111	71	182
	Im	10	1	11

Summary

In this section, I identified various discourses that the students and the teacher engaged in while they were participating in whole classroom and small group discussions that implemented photographs with/without CRSs. The teacher often started by asking students to *observe* the photographs. The students responded by *describing* what they saw in the photographs. When the teacher asked *conceptual questions*, the students often responded with *Visual Reasoning* discourse by developing their initial stage of reasoning. Higher-order thinking discourses such as *Visual Spatial Thinking* or *Applying a Scientific Concept* often occurred in the later of the discussions as their reasoning became sophisticated.

2. Student Misconceptions about *Day-Night* and *Cause of Seasons*

In Chapter 2, I reviewed previous studies about misconceptions of day-night and seasonal change on earth. Although the previous studies had reported several misconceptions, it is still valuable to look at the ideas of participating students in this study about the concepts. Some ideas are similar to those reported in previous research, but there are others that are new.

In this section, I present the 6^{th} graders' ideas about day-night and cause of seasons found mainly from the conception pre- and post-tests. Based on the student written responses and their drawings on the survey, I describe their misconceptions about reasons for day-night, length of daytime, and seasonal change on earth. While I was observing the students in classroom discussion, I discovered several misconceptions that were not found in the conception survey. Those misconceptions found from the classroom observation are added in the later part of this section.

Student Ideas about the Concept of Day-Night

In the conception survey, students were asked to write the definition of day and night and the reason for the day-night cycle on earth. Below are the several notions that were found in the student responses. In the quotes, *Int* represents the intervention group, and *Trad* represents the traditional group. Student number and whether it was from pre-test or post-test are also presented.

1) Day and night happen on earth due to people's needs. This may be the most basic and naïve notion. Students simply described day and night with people's behavior:

> Daytime: days of work during the week and fun times on the weekends.
> Nighttime: time of relaxation, rest, and play sometimes. (Int2, S35, pre)
> Daytime: morning, wake up, Nighttime: evening, sleeptime (Int2, S38, pre)
> Daytime: sun up moon is down, we are awake and eating breakfast, lunch and maybe dinner. Nighttime: sun is down moon is up, we are sleeping and eating dinner and getting ready for bed. (Int2, S33, pre)

For the survey question of "why day and night happen on earth?", the students described that day and night happen on earth because people need them to live:

> It happens because there is time for you to go to bed and for you to enjoy the day. (Int2, S23, pre)
> Because people need day and night (Trad1, S57, pre)
> Day and night happen on earth because if we didn't have day then we would be sleeping all the time and if we didn't have night the same day would go on and on forever. (Int1,S5,pre)

> I think it happens so we can see in the day and so we can sleep in the night. (Int1, S4,pre)
>
> I think day and night happen because if there was no night we wouldn't know when to sleep. Also daytime we wouldn't know when to get up. (Trad1, S43, post)
>
> I think day and night happen because without them, people wouldn't be able to sleep and would get a lot of sunburn. (Trad1, S41, post)
>
> So we can see our way in the day and go to bed at night. (Trad1, S54, post)
>
> To keep ever one and thing alive. (Int1, S16, pre)

The responses were from their daily experiences of what they did during daytime or nighttime. They simply described people's behavior for the reason for the physical phenomena, day and night. This notion is very primitive and non-scientific. This notion was often more observed in the pre-test than in the post-test.

2) Day is light out and night is dark out. In this notion, the students simply described lightness or darkness for the concept of daytime and nighttime. This notion is naïve and non-scientific.

> Daytime is bright and nighttime is dark. (Trad1, S49, post)
>
> Day-when it is light out with no stars. Night-when it is dark out with stars (Trad1, S58, pre)
>
> Day is noon and night is evening (Trad2, S75, pre)
>
> Daytime is when it is early and nighttime is when it is late. (Int1, S15, pre)

3) Day is when the sun is out and night is when the moon is out. In this notion, students used the words, the *sun* and the *moon*. Although this notion is somewhat advanced than the previous ones, it is still a very naïve conception.

> Daytime happens because we have sun. Nighttime happens because we have moon. (Trad1, S48, post)

Day is when the sun comes out and brings light and heat. Night is when the moon and stars come out and it cools down. (Int2, S26, pre)

(Int2, S26, pre)

Daytime is when the sun is up and it is light out. Nighttime is when the moon is up and it is dark out. (Int2, S27, pre)

Day is when the America faces the sun. Night is when the America faces the moon. (Trad1, S46, pre)

4) Day is when the sun is up and night is when the sun is down. In this notion, students focused on the existence of the sun to explain day and night, and did not consider the moon.

Daytime is when the sun is all the way in the sky and nighttime is when you can't see the sun. (Int2, S23, pre)

Daytime is when the sun is out, and nighttime is when the sun is not out. (Int2, S21, pre; Trad1, S58, post)

Daytime is when the sun is up, and nighttime is when the sun is down. (Int2, S31, pre)

Day and night happen because when the sun goes down it makes night, when sun comes up and hits the earth it becomes day. (Int1, S5, post)

This notion is not logically wrong. It is true that we call daytime the time when the sun is out in the sky and nighttime the time from when the sun sets until it rises again. This notion, however, is limited to the ground-based view, and the students could not fully explain *why* day and night actually happen.

5) Day and night happen because the moon revolves around the earth. Night happens when the moon blocks the sunlight. Some students showed a misconception that the moon has something to do with the Earth's day and night. They thought that day and night happen on earth due to the moon's revolution around the earth. Sometimes, partial understanding of the concept of solar eclipse confused them with the concept of night.

> Day: when the sun is not blocked by the sun. Night: when the moon blocks the sun. (Int1, S16, pre)
>
> Day and night happens because of the moon's rotation around the earth. (Trad2, S71, post)

6) Day and night happen on earth due to an interaction between the sun and the moon. This notion was rare and found in few student responses.

> [Day and night happens] Because as the sun moves closer the moon pulls further away. And when the moon pulls closer the sun fades from our side. (Trad3, S96, post)

7) Day and night happen on earth because of the earth's rotation on its axis. The side of the earth that faces the sun is daytime and the other side of the earth that does not face the sun is nighttime. This is a scientifically correct explanation for the concept of day and night.

> I think day and night happen on earth because the earth rotates on its axis and different parts of earth are facing the sun at different times. (Trad1, S56, post)
>
> I think day and night happen because of Earth's rotation. During day and night the earth is facing a certain way, towards the sun in day and away in night. (Int1, S8, post)

> I think day and night happen because since the earth is rotating, it will get some light on one half of the earth and the other half is night because it is not getting light. (Int1, S4, post)

This notion shows that the students scientifically correctly understand why day and night happens on earth and are able to describe with a space-based view which side would be day or night. The correct conception was found more in post-test than in pre-test. A few students had a mixed conception that combined the reason for day-night with the concept of seasonal change. These students responded that day and night happen on earth because of the earth's *tilted* axis.

> I think day and night happen on earth because the earth is tilted on its axis so when the earth's axis is tilted away from the sun it is night, and when it is tilted toward the sun it is day. (Int1, S11, post)
>
> [Day and night happen on earth] because of earth's tilt. (Trad3, S98, post)

Student Ideas about the Concept of Length of Daytime

Many students had difficulties with understanding the reason for the different length of daytime. In the pre-test, the common response to the survey question about the length of daytime was that the length of daytime was the same at any place on earth. In the post-test, many students responded that it differed depending on places. Some students explained it correctly with the earth's tilted rotational axis. But, some students mentioned only the earth's rotation or the earth's axis with limited explanations, and many others still could not give scientific explanation.

To the next survey question, "How does the time of sunrise and sunset change throughout the year in XXX, and why?" students had several notions described below.

1) It happens because of seasons. In this naïve notion, students responded that the time of sunrise and sunset changes because of different seasons. They simply described the phenomena that is caused by different seasons, but could not explain *why* it actually happens.

> Because of the seasons: cold=shorter, and hot=longer (Int1, S10, post)
>
> It changes a minute every day. It does this because a different season is coming and seasons change a lot of things. (Int1, S7, post)
>
> How it changes is because of seasons. If it's winter, the days are shorter, so the sunset comes faster, but if it's summer, the days are longer and sunrise comes longer. (Trad1, S60, pre)
>
> Sunrise and sunset change throughout the year because of the seasons. When it is winter, there is shorter days, and the sun rises earlier, and the sun sets earlier. In summer the sun rises later and sets later. … (Int2, S23, post)

To answer for the question, the students simply rearranged the information that the question provided. The survey question was meant: Q. Why does the time of sunrise and sunset change in different seasons (throughout the year)?

Then, their response was: A: The time of sunrise and sunset change *because* seasons change.

So, this notion does not contain any more than that the question provides. This kind of response may be often observed in young students.

2) It happens because of daylight saving time. In this notion, students brought their experience of daylight saving to explain why the time of sunrise and sunset changes throughout the year. This misconception was very common among many students and often strongly persistent even after having the instruction.

> It changes because when we have daylight savings time the time will go back an hour and the sun will go down earlier and come up later. (Int1, S5, post)
>
> It changes because we have to change the clocks in spring and in fall because of day light savings. (Int1, S3, post)
>
> There is always a part of the year where we go back in time by an hour and eventually go ahead an hour after. (Int2, S27, pre)
>
> The time of sunrise and sunset change throughout the year in Westfield, MA, because of day light savings, which means the sun sets earlier. (Int2, S32, pre)
>
> It changes because when the seasons change the sunsets earlier because of daylight savings time. (Trad1,1 S46, pre)

People established the Daylight Saving Time for people's convenience and needs, so they can have afternoons with more daylight and mornings with less. However, many young children misunderstood that the time of sunrise and sunset changes *due to* the daylight saving time.

3) It happens because of the sun's gravitational pull on earth. This is an interesting misconception to mention although it was found in a small number of students.

> The sunset changes because [of] the suns gravitational pull on earth [it] makes earth come closer to the sun in summer and in the winter the sun repels earth a tiny bit. (Int2, S22, pre)

In the above quote, the word, *the sun's gravitational pull*, represents a common misconception found in many students—that the distance between the sun and the earth is the reason for the seasons and somehow it affects the length of daytime on earth.

4) It happens because of the earth's tilted rotational axis. The hemisphere that is tilted toward the sun has a longer length of daytime and the hemisphere that is tilted away from the sun has a shorter length of daytime. This is a scientifically correct conception for the concept of different length of daytime on earth.

During the summer in XXX, MA there is longer daytime. In the winter, there is shorter daytime. This happens because as the earth revolves around the sun on its axis the North Pole or South Pole are facing toward the sun. This causes XXX, MA to be in darkness (nighttime) longer or light (daytime) longer. (Int1, S1, post)

The sunrise and sunset change throughout the year in XXX, MA because of the axis on the earth and which way it is tilted. (Int2, S33, post)

Student Ideas about the Concept of Cause of Seasonal Change

In the pre- and post-tests, students were asked to write a reason for seasonal change on earth and to draw a diagram to explain their thought. Misconceptions about this concept have been well documented in previous literature as seen in Chapter 2. In addition to the well-known misconceptions, several new ones were discovered in this study.

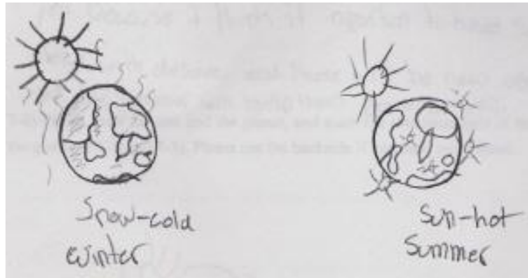
1) Seasonal change is caused by weather. This is a very naïve conception. It was surprising that an unexpectedly large number of students provided this response. This was found more in the pre-test than the post-test. However, a few students still gave this notion in the post-test.

What I think causes the seasons would be the weather. I think that because in the spring sometimes it's hot & cold, in the summer it's always hot, in the winter it's always cold, and in the fall it's hot & cold like the spring. (Int2, S36, post)

What causes the seasons is the weather because winter is cold and makes it snows and in the summer time it's really really hot outside. That's what causes the seasons. (Trad2, S75, pre)

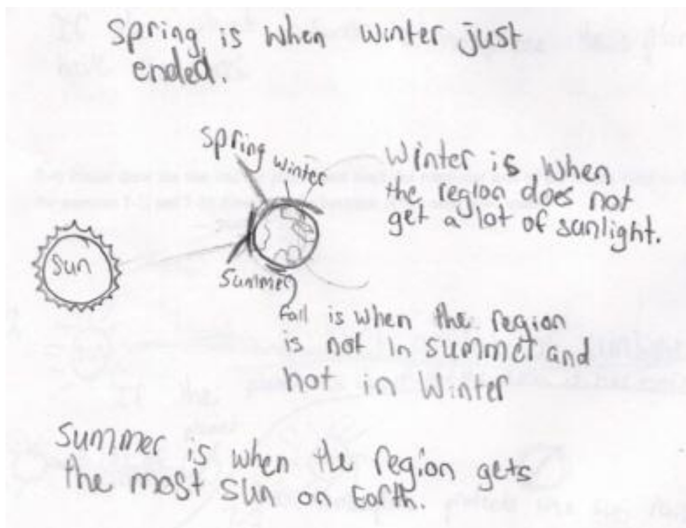
The weather causes the seasons because if it's not hot in the summer then it's not like summer. If it doesn't snow in the winter it's just like a longer fall. (Trad2, S63, pre)

I think there are seasons because of the weather and time of year. (Int2, S33, pre)

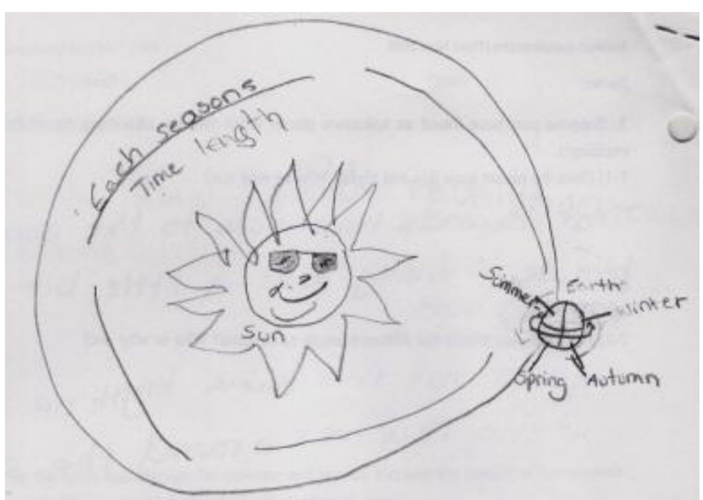


(Int2, S33, pre)

2) The earth has four different areas having each different season. In this naïve notion, students thought that the earth is divided into four different areas having each different season.



(Int2, S24, pre)



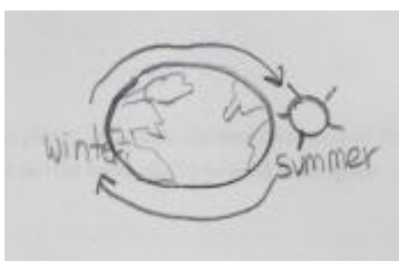
(Trad1, S46, post)

This notion was reported by Dunlop (2000) that surveyed 67 students aged between 7 and 14. He reported that a small number of students had this notion and held the same even after they had instruction. In my study, this was also found in a small number of students, but it seems that it is one of common misconceptions among young students about seasons on earth. This notion might have come from the confusion between the concepts of *season* and *climate*.

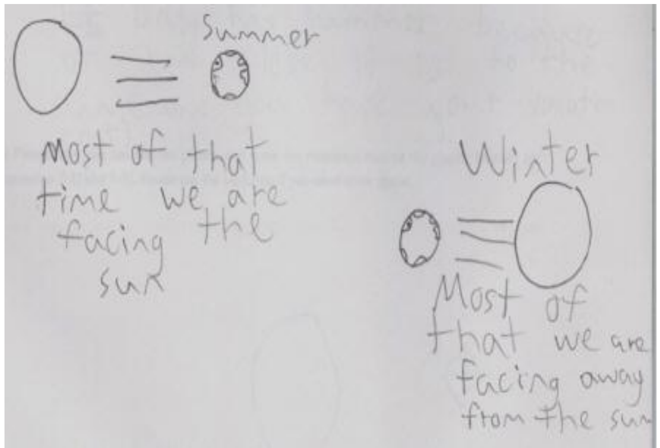
3) Summer is when the earth faces the sun and winter is when the earth faces away from the sun. This notion is confounded with the concept of day and night. The students who had this notion thought that when the earth faces the sun, it is summer (which is scientifically *daytime*), and when the earth faces away from the sun, it is winter (which is scientifically *nighttime*) as can be seen in the below quote:

> When the sun goes behind our surface, it gets to be dark and cold. That's when winter comes around. When the sun comes in front of the earth, it gets to be hot so it turns into summer. (Int2, S35, pre)

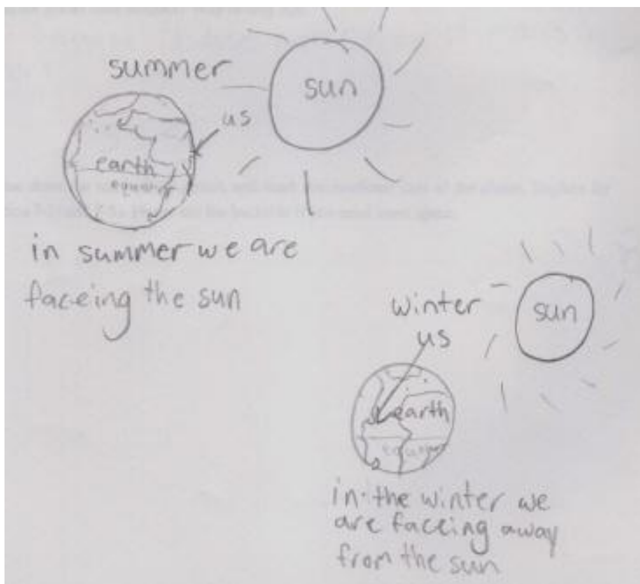
The students drew diagrams that showed summer as the earth facing the sun and winter as the earth facing away from the sun.



(Trad1, S51, pre)

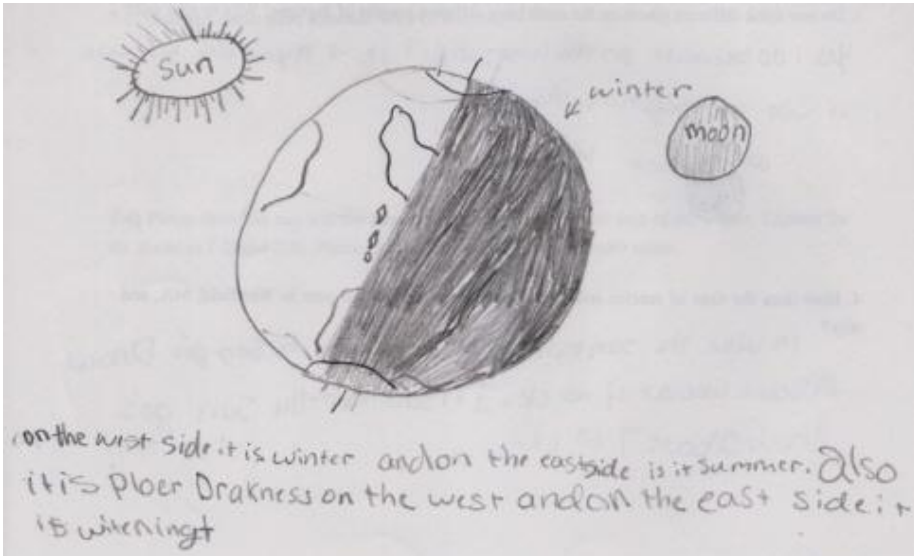


(Int2, S27, pre)



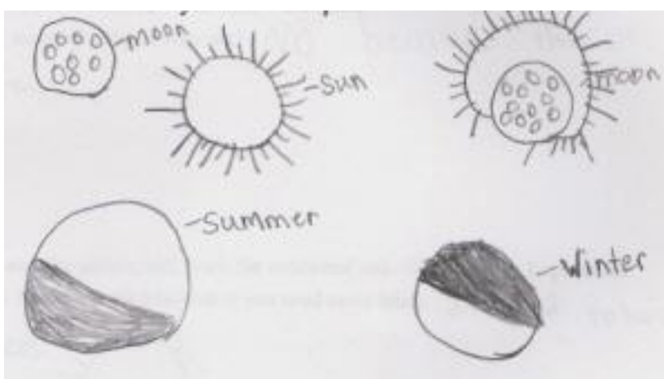
(Int2, S28, pre)

4) Summer is when the earth faces the sun and winter is when the earth faces the moon. This is similar to the above misconception that is confounded with the concept of day and night. In addition, the students who had this notion related the concept of night to the moon. For example, in the below diagram, the student explained that the bright side of the earth that faces the sun is summer and the dark side that faces the moon is winter.



(Int2, S29, post)

5) Winter happens on earth as the moon blocks sunlight. There was another misconception that related the moon as the reason for seasons on earth. For example, the below student drawing shows that winter happens when the moon covers the sun and the earth gets dark. This is a confounding conception with the concept of a solar eclipse.



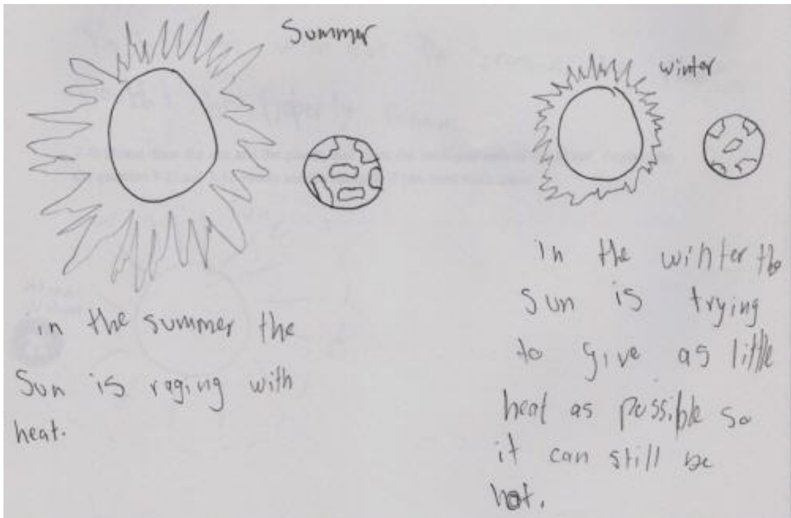
(Trad1, S49, pre)

6) The sun is related to seasons on earth. Students showed various misconceptions about the sun relating to seasons on earth. They thought that the brightness of the sun, the speed of its revolution around the earth, or the size of the sun affects the seasons on earth.

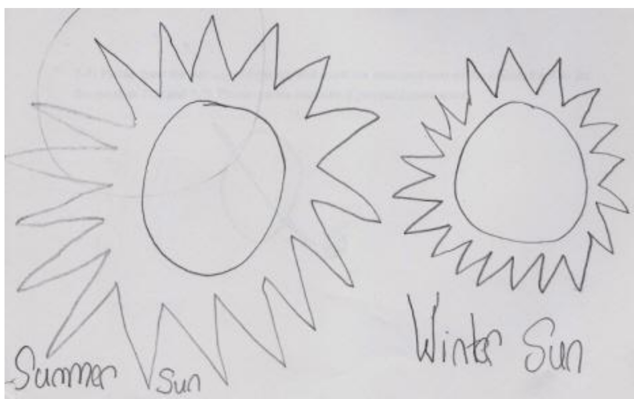
i. Brightness of the sun affects seasons on earth.

i-1. Summer sun is brighter and winter sun is darker.

I think the brightness of the sun changes the seasons. (Int1, S9, pre)



(Trad1, S41, pre)

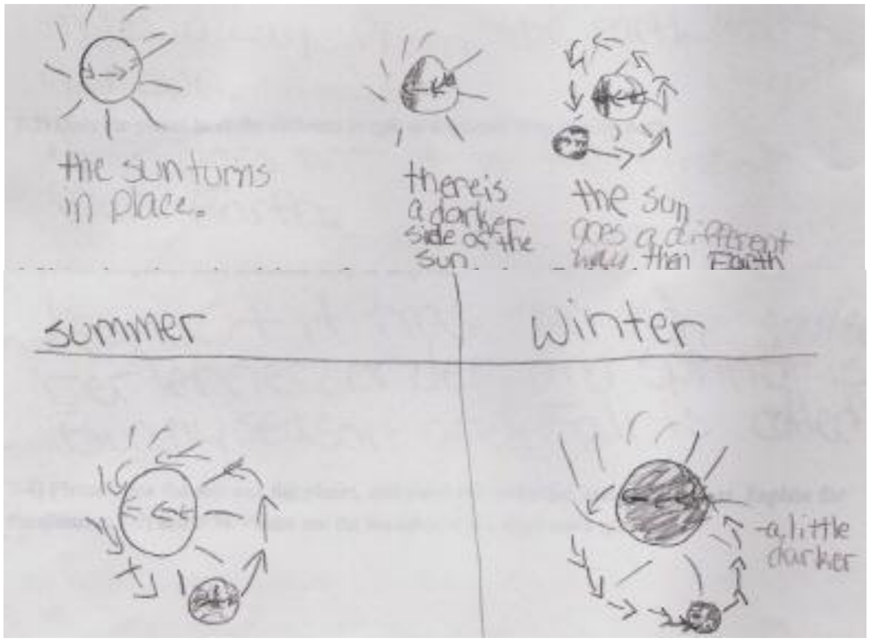


(Int2, S26, pre)

In the above diagrams, students depicted the sun's rays as larger representing brighter sunlight for summer and smaller representing less bright sunlight for winter.

i-2. There is a darker side of the sun. Winter happens when the earth faces the darker side of the sun.

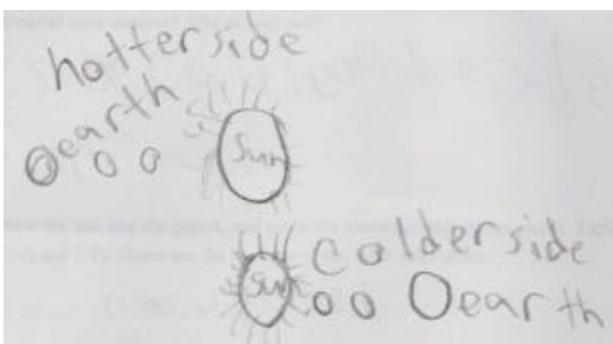
I think that the sun causes the season. There is a darker side of the sun. ...(Int1, S7, pre)



(Int1, S7, pre)

i-3. The sun has a hotter and a colder side. Whether summer or winter is decided which side of the sun the earth faces.

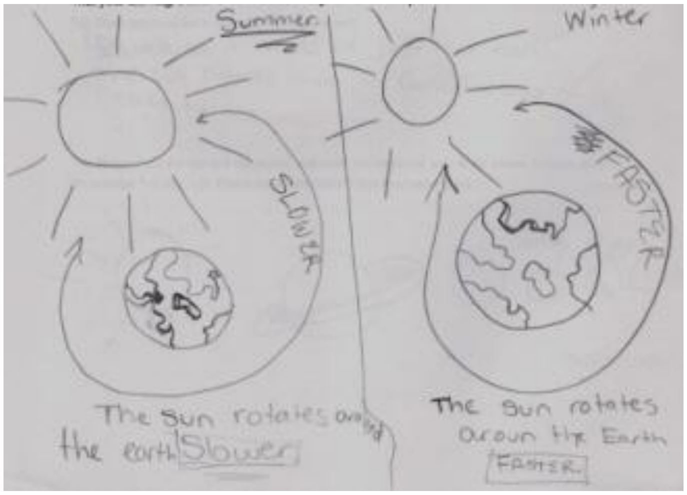
Which side of the sun we’re on. (Int1, S10, pre)



(Int1, S10, pre)

ii. Speed of the sun’s revolution around the earth affects seasons on earth.

Summer is when the sun rotates around the earth slower. Winter is when the sun rotates around the earth faster. (Int2, S32, pre)



(Int2, S32, pre)

This is an interesting misconception. The student seemed having the conception that the daytime is longer in summer and shorter in winter. But then, she had the conception of Ptolemaic theory and thought that the sun revolves around the earth.

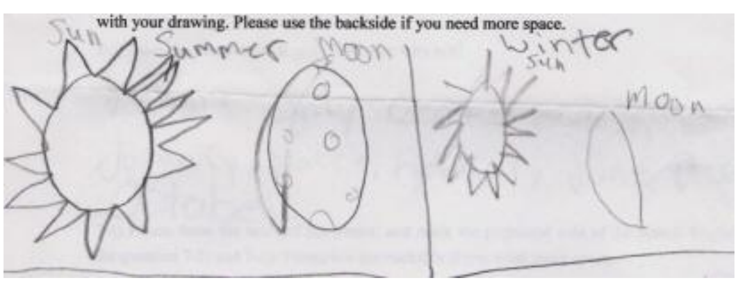
iii. Size of the sun: Summer sun is bigger than winter sun.

(Trad3, S86, post)

In the above diagram, the student represented that the sun is bigger in summer and is smaller in winter.

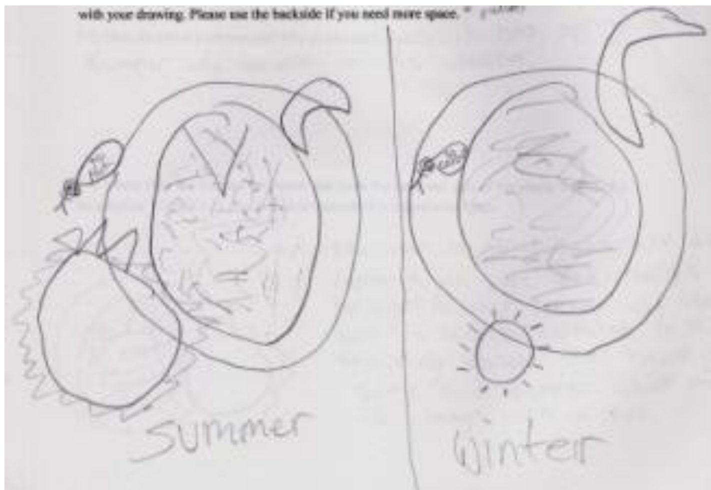
The first examples (i-1, i-2, i-3) are related to the brightness of the sun. The students with this notion had the misconceptions that the brightness of the sun changes and affects seasons on earth, or that the sun has a hotter and colder/darker side, or that the season on earth is decided depending on which side of the sun the earth faces. The second example (ii) shows a very interesting misconception. Student in this notion had the misconception that the sun revolves around the earth, and in addition, thought that its speed affects seasons on earth. She had a misconception that it is summer when the sun moves around the earth slowly and it is winter when the sun moves around the earth faster. The student might have thought that the sun would take longer to pass by the earth (because it moves slowly) so the earth gets longer sunlight, which makes summer on earth, and vice versa. The last example (iii) shows a misconception about the size of the sun relating to the season on earth—the bigger the sun, the hotter on earth (summer), and the smaller the sun, the colder on earth (winter).

7) Both the sun and the moon affect the seasons on earth. Some students had combined notions of the sun and the moon affecting seasons on earth. For example, a student drew a diagram and wrote that, "In the summer, the sun is always shinning so that's why I put the sun big. And in the summer also there pretty much always a full moon. The sun in winter is more little because it doesn't get that much sun it's always covered up by clouds. And the moon is small because the temperature. (Int2, S36, pre)"



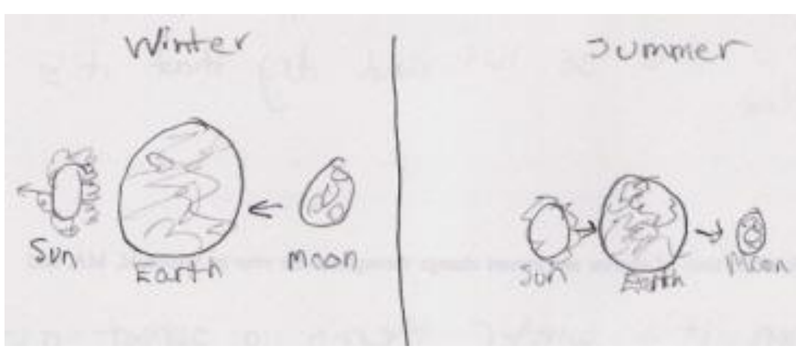
(Int2, S36, pre)

The student thought that both the sun and the moon are bigger in summer and become smaller in winter. Another student drew a diagram as below in which the sun is bigger and the moon is smaller in summer, and the sun is smaller and the moon is bigger in winter.



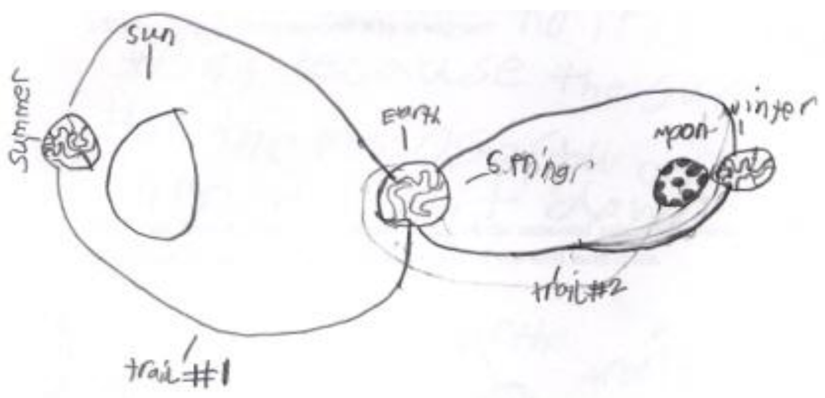
(Trad3, S97, pre)

In the post-test, this student held the conception that both the sun and the moon affect the seasons on earth, and she drew a diagram representing that the moon moving close to the earth and the sun moving away from the earth in winter, and the moon moving away from the earth and the sun moving closer to the earth in summer. The student wrote on the survey, “Maybe when the earth has a rotation, the moon is seen more than the sun which causes winter on earth. (Trad3, S97, post)”



(Trad3, S97, post)

Another student wrote, “I think the sun and the moon causes the seasons because when the sun and the moon and the earth move, it gets to warmer and then colder climates so when the world revolves around the sun, it gets warmer and when it goes around the moon, it gets colder, and in the middle, it is not too warm and not too cold so it’s spring time when it’s in the middle of the sun and the moon. (Trad3, S88, pre).” The student drew the diagram as below that showed an interesting notion: it is summer when the earth moves around the sun, and it is winter when the earth moves around the moon.



(Trad3, S88, pre)

As can be seen in the above responses, the students tended to connect the sun to summer and the moon to winter on earth. This is a similar misconception that was found in the concept of day and night. The students tended to connect the sun to daytime and the moon to nighttime on earth. The students seemed to simply connect the phenomena to representative characteristics of the astronomical objects (Table 7), and that leaded to develop misconceptions.

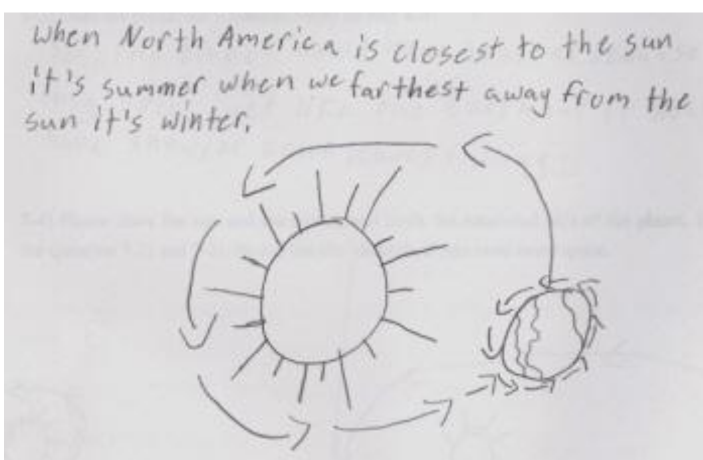
Table 7. Student misconceptions about the sun and the moon in regard to the concepts of day-night and seasons on earth

Objects	Characteristics: phenomena on earth	
	Brightness	Temperature
The Sun	Bright: Daytime on earth	Hot : Summer on earth
The moon	Dark: Nighttime on earth	Cold : Winter on earth

8) Distance between the sun and the earth causes the seasons on earth. It is summer when the sun is closer to the earth, and it is winter when it is further. This is a well-known misconception. It may be the most common and strongest misconception of all. Some student quotes that show this misconception are:

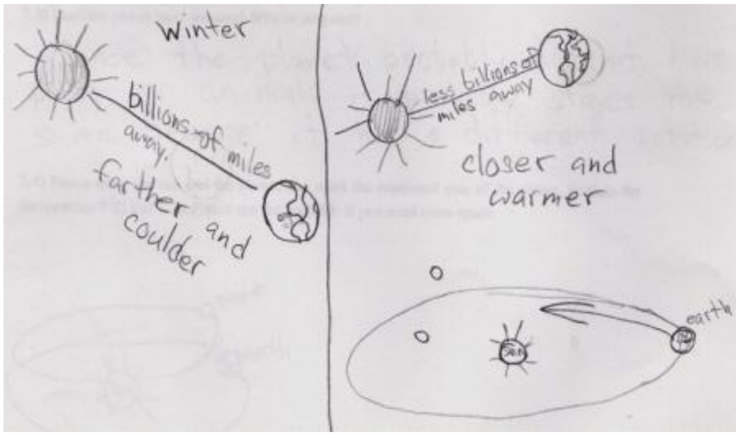
> I think the seasons change by move further or closer to the sun. (Int1, S16, pre)
> The seasons are caused by the distance between the sun and the earth and where the earth is. (Int1, S2, post)

The students with this notion mostly drew an orbit as an oval shape as below and explained that it is summer when the distance is closer and it is winter when the distance is further.



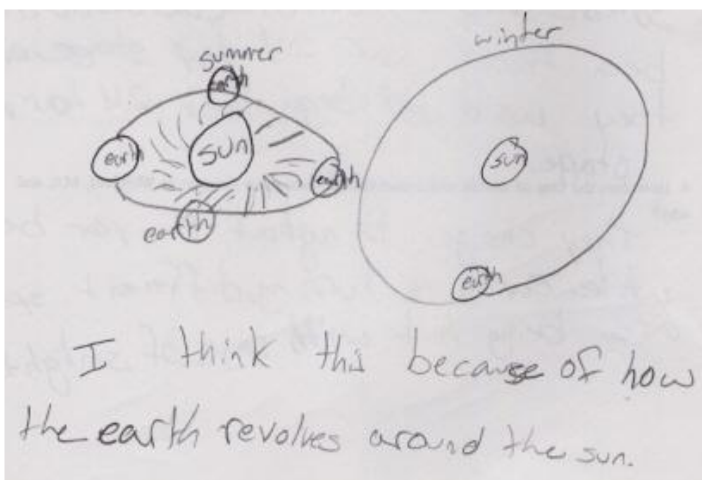
(Trad1, S57, pre)

One of the students specifically mentioned an oval shape of the orbit: “What I think causes the season is when we get farther away from the sun. When we go around the sun we don’t go in a perfect circle we go in an oval shape. (Int2, S23, pre)”



(Int2, S23, pre)

On the other hand, some students drew separate orbits with a small circle for summer and a large circle for winter as the below diagram.

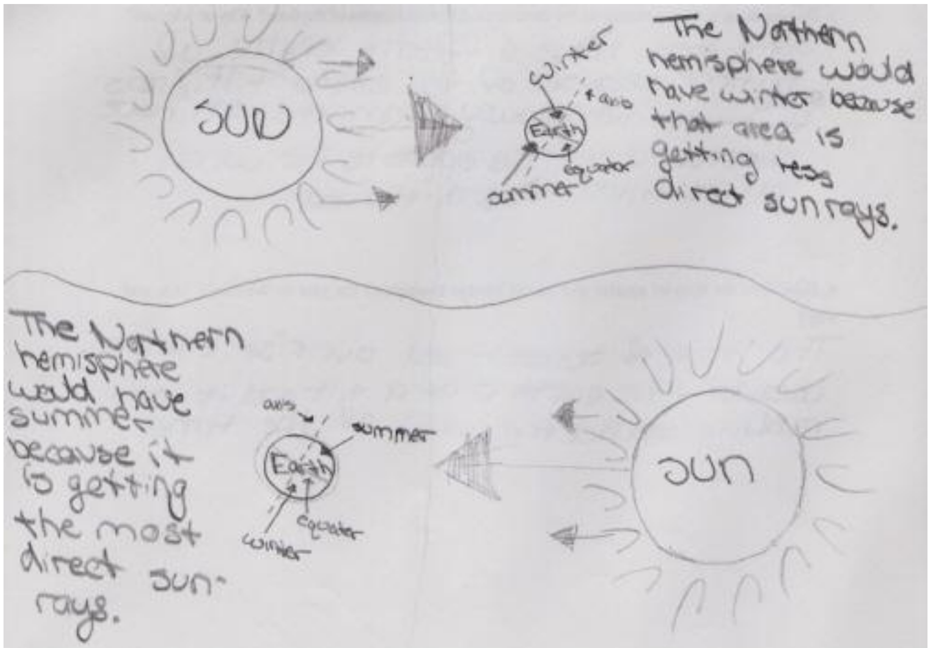


(Int2, S35, post)

This notion has been reported as a prevalent and persistent misconception among many aged groups from young kids to even adults (Atwood and Atwood, 1996; Baxter, 1989; Dunlop, 2000; Sadler, 1992; Schneps, 1989).

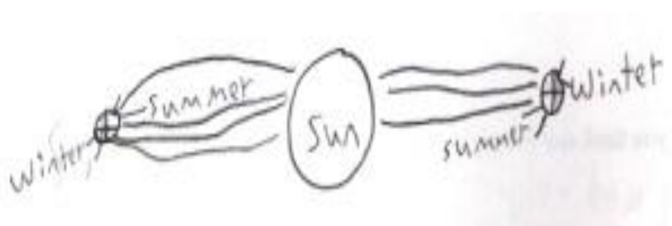
9) Seasonal change on earth is caused by the earth’s tilted axis. When the Northern Hemisphere is tilted toward the sun, it receives more direct and longer sunlight, so it is *summer in the Northern Hemisphere and winter in the Southern Hemisphere. When the Northern Hemisphere is tilted away from the sun, it receives less direct and shorter sunlight, so it is winter in the Northern Hemisphere and summer in the Southern Hemisphere.* This is a scientifically correct conception. Some students simply wrote that the seasonal change on earth is caused by the earth's tilted axis without further explanation. But others were able to provide detailed explanation describing why the tilt is the reason for the seasonal change and how the seasons are different between the Northern and the Southern Hemispheres. This notion was found more frequently in the post-test than in pre-test:

> I think the main reason for seasons is the tilt of earth's axis. This causes sunlight to hit the earth at an angle, making some parts hotter than others. This causes different seasons in different parts of the earth. (Int1, S1, post)
>
> When the earth's axis is tilted toward the sun, it is summer because it is getting more sunlight, and when the axis is facing away from the sun, it is winter because it is getting less sunlight. (Int2, S33, post)
>
> The earth rotation on its axis causes the seasons on earth. The areas on earth that are tilted toward the sun would have summer. The areas that are tilted away would have winter. (Int1, S6, post)



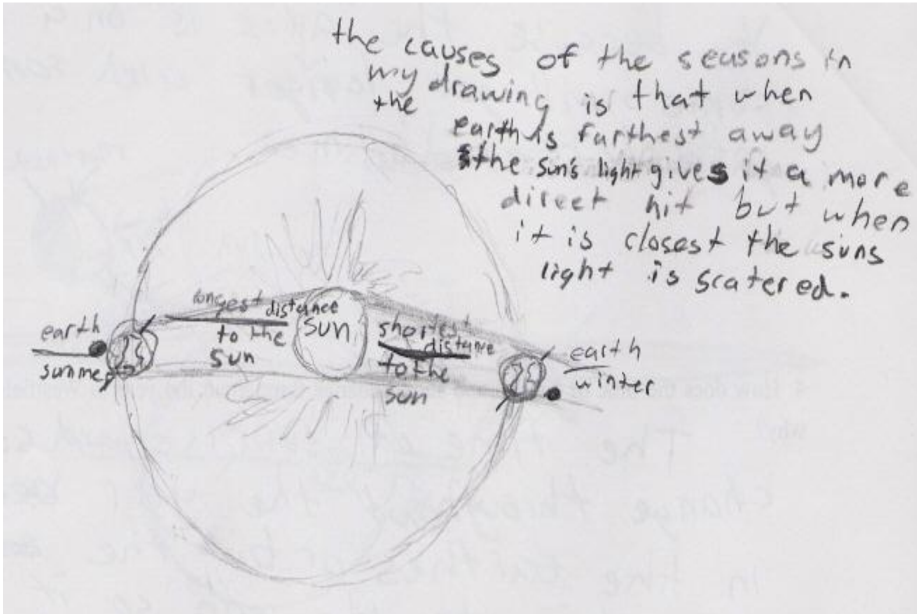
(Int1, S6, post)

> Summer happens because of the tilt and how it's facing the sun. It's lit up more by the way it's facing the sun. Winter happens because of the tilt and how Earth faces the sun. Since the North Pole is facing away, it becomes more cold by the lack of direct sunlight. (Int2, S27, post)



(Int2, S27, post)

10) Distance between the sun and the earth causes the seasons on earth. When it is closer, the earth gets scattered sunlight, which causes winter on earth, and when it is further, the earth gets more direct sunlight, which causes summer on earth. One of the students in the post-test wrote, "The causes of the seasons in my drawing is that when earth is furthest away, the sun's light gives it a more direct hit, but when it is closest the suns light is scattered. (Int1, S4, post)," and he drew a diagram as below.



(Int1, S4, post)

This is a very interesting notion. This notion seems to be created by the combination of several conceptions. This student thought that the distance was the reason for the season, but also had the conception of direct sunlight causing high temperature on the earth surface. This may be a hybrid model that was combined his prior knowledge with what he learned recently. The students in this class learned that the distance between the earth and the sun is slightly closer in December than in June (so the distance is not a reason for seasonal change) although the orbit is almost circular. The student who drew the above diagram knew that the distance is closer in winter than in summer (in the Northern Hemisphere). In addition, he learned that the surface temperature rises when it receives more direct sunlight. But, he had the strong misconception about distance being for the reason for the seasons. By combining all three conceptions, he reached such a hybrid model that the light may be scattered when it is closer so it is winter, and it may be direct when it is further so it is summer, as represented in the above diagram.

Misconceptions found from Classroom Observations

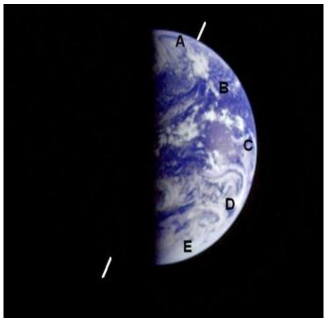
While observing classroom discussion in the two intervention classes, several misconceptions that were not found in the conception survey were discovered. In this last part of the section, I briefly summarize three major misconceptions found from the classroom observations.

1) *Seasonal change on earth is caused by the earth's tilted axis. When the axis is tilted toward the sun, it is closer, and when the axis is tilted away, it is further from the sun.*

This notion was found from student discourses: "S6: Shouldn't be am, the midnight sun and polar darkness switched? Like polar darkness should be at the North Pole and midnight sun should be at the South Pole? Cause the South Pole is right where the axis ends and that would be the closest to the sun and at the top of the axis it would be farther away from the sun and should get less sun light (Int1, day10, 00:43)," and "S36: I chose D because the more the earth is tilted that way, the sun is facing that way, the sun is closer to that side (Int2, day19, 00:26)."

This may be a hybrid model that was combined the strong misconception about the distance with the new scientific conception about the earth's tilt. These students learned that the tilted axis is the reason for seasons, but they also had a strong misconception that the distance may be the reason for seasons. Therefore, they applied the concept of the tilt to the conception about distance, and thought that the tilted axis made the distance between the sun and the earth different enough to cause the seasonal change on earth. This might be due to a *phenomenological primitive* (diSessa, 1993), which is thought to be "further" when the word "tilted *away*" is used and to be "closer" when the word "tilted *toward*" is used.

2) The next notion was found when the students were discussing the below question:



Q. Compare the length of daytime for the place of A, B, C, D, and E.

a) The length of daytime is the same for the place of A, B, C, D and E.

b) The length of daytime is the longest at C, then at B & D, and it is the shortest at A & E.

c) The length of daytime is the longest at A, then B, then C, then D, and it is the shortest at E.

d) The length of daytime is the longest at E, then D, then C, then B, and it is the shortest at A.

e) None of the above.

A common misconception found from this question was that *the place C has the longest daytime because it has the furthest distance from the boundary between the dark and the bright sides.* The below episode, taken at the intervention class 1 on day 13, shows some of the student conversations about this question revealing the misconception. This episode happened after the histogram result showed that about half the students chose the choice b. (In the intervention class 2, a majority, 15 out of 16 students, chose the choice b for the same question.) The teacher, Mary, was asking the students to answer the reasons why they chose b.

> <u>S14: A and E would take the shortest time to go past this line [pointing at the line splitting lit and dark side of the earth]. Then B and D would. Then C has the longest time to go around.</u> [00:35:29.25] (misconception) [VR]
>
> T: So you're measuring from where the day ends and night begins, you're measuring the distance from this point here darkness to the edge of the earth's surface.
>
> S14: [Nodding]

T: That’s how you were figuring it out. Okay anyone else that chose B as your choice wants to talk about how they came up with their decision? Does everybody understand what S14 was saying?

Ss: Yeah. Mmm-hmmm.

T: Okay. Okay, S6, you chose it too?

S6: I chose b and I thought of it like a race and um, the um start of night, the darker side would be like a finish line and A and E would finish first so that would be the shortest time in the day, and then B and D would finish second (inaudible) more time of day but not the longest, and C would have the longest time of day because it finished last and it was the furthest from the line. [00:36:49.23] (misconception) [VR]

T: So yours was similar to what S14 was saying too. You were measuring from that where we see the night and day division.

S6: [Nodding]

S11: Um, well can I use the globe up there?

T: You can.

S11: [00:37:19.11] [She went up to the front to use the globe.] Um the earth is tilted, (pause) the earth is tilted like that, yeah and C’s over here [pointing at the equator area on the globe], B’s up here, A’s up here, and D’s down there and E. A and E would have the shortest time around because they only have to go a little bit and then it would be B and D because they have a shorter time around, a lot shorter, but it's not the longest, and C would be the longest because it's right here and it has to go all the way around to get back. (misconception)

Although S11 mentioned the earth’s tilted axis and the earth spinning around its axis, she was considering the day-night line for the earth’s axis and her reasoning was static (Table 8). While listening to her explanation, S16 realized that the place A would have the longest daytime because it would have white night. S16 was able to apply dynamic visual reasoning after listening to S11’s explanation.

(Continued from the above episode)

T: Okay. Anymore people that chose b that want to explain why they chose it.

S16: I want to change my answer to c because A does look longer and looks like A is having white night at (inaudible). (After seeing S11's explanation, he found choice b was wrong and wanted to change it to c.) [dyVR]

In the later part of this conversation, some other students also correctly described why the place A had the longest daytime. The episode is continued from the above.

S1: [went up to the computer] I thought that um A would be the longest because it's white night up here which would give it longer hours of light and then B would be the next shortest because it's getting closer to the bottom to be polar darkness and then C is, would be the next longest, I mean the shortest because um, because it’s getting closer to polar darkness, too. And then, D would have really shorter hours of daylight because it’s really closer to polar darkness. E is in polar darkness right now, it’s at the South Pole. So it would just be like really short hours of day light.

T: So your choice was c also?

S1: Yeah.

T: Okay, S8.

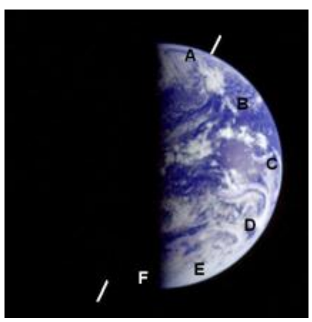
S8: [went up to the computer] I chose c because um, A is like right at the North Pole and say the sun is like right over here [pointing the right place] it would be facing more towards the sun and B would be like the next longest, like it's not as long as A, because it would also just like (inaudible) around little bit I don't know but, and E isn’t directly at the South Pole, it's at the right of the South Pole, it's like where the axis is, so it spins around the axis and A is right on the North Pole so it's like on the white night [pointing A] and D is more towards like the South Pole so it would have shorter days because the sun would like, like it would always be dark. But I don’t know, do you know how long it’s light out? Okay, so it wouldn’t ever really get light out in the South Pole, so E would almost be like polar darkness or C would be like really at noon almost right now. [Now, she is using the globe.] So if it were like, it had to like, went around (inaudible) the equator, (inaudible) A is north pole so it would just have little (unclear) light but it will have the daytime all the time. [00:43:14.03]

Table 8. Different reasonings applied by the concept of tilted axis, dynamic visual reasoning or misconception about the day-night line

Misconception that the earth spins around the day-night line	The concept of the earth spinning around the *tilted* axis	Dynamic Visual Reasoning	Student Discourse (Student reasoning)
O	X	X	The place C would have the longest daytime, and then B&D, and then A&E. (Applying simple visual reasoning. Thinking that a place that has a longer bright distance from the day-night line has longer daytime, and a place that has a shorter bright distance from the day-night line has shorter daytime.)
O	X	O	All the places would have same length of daytime. (The earth is spinning around the day-night line.)
X	O	O	The place A would have longest daytime, and then B, then C, then D, and E would have shortest daytime. (Correctly thinking that the earth is spinning around its tilted axis.)

To answer for this question scientifically correctly, dynamic thinking may need to be applied. The students who used only visual reasoning (VR), for example S14 and S6, interpreted that the place C had the longest daytime because it was the furthest from the day-night line, therefore they thought that it took more time before it became dark. On the other hand, as can be seen in the case of S1 and S8, the students who applied dynamic visual reasoning could correctly interpret the image, simulating the earth to spin around the tilted axis in their mind's eye. Therefore, applying VR solo can be reached through a partial understanding of a scientific concept and it could create a misconception. The higher level of visual thinking, dynamic VR or dynamic VST, may be required to interpret the scientific concept correctly. However, if someone had applied dynamic visual reasoning but did not have the correct conception that the earth spins around its *tilted* axis, he would have reached another misconception that all the places had same length of daytime. Table 8 summarizes the different reasonings for the cases by whether dynamic visual reasoning or the concept of the tilted axis was correctly applied or not.

3) Another interesting misconception was found when the students were discussing the question about the hottest place among the places in the below image.



Q. Where do you think is the hottest place among the places of A, B, C, D, E, and F? Why?

The following is an episode from the intervention class 2 on day 15. The question was presented to the students and asked them to work on it as small groups. The episode is from one of the small groups discussing the question.

S27: Is it C or D? [00:20:59.20]

S35: Yeah, it could be in between C and D. [00:21:04.07]

S27: Looking at equator, D is in the Southern Hemisphere, the Southern Hemisphere itself is facing away. [00:21:06.03]

(inaudible Ss talk)

S27: I think C [with raising his hand, looking at other group members. No one raised hands except him]. [00:21:28.24]

S35: I think C and D. [00:21:32.05]

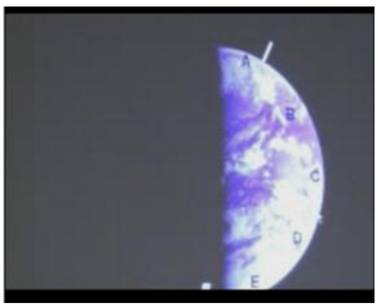
S27: (inaudible)

S35: yeah, but it all equator. It just doesn't matter cause it's (inaudible). [00:21:40.22]

S27: No, no, it is closer [looking at the screen]. [00:21:47.11]

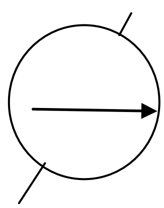
[they come up to the screen] [00:21:52.13]

S35: S27, look. If you look right here, say that's where it is, right? If you look at it, it's gonna go around the sun. So it could be C or D. [00:22:05.04]



[pointing a spot between the place C and D on the screen]

S27: Equator is like this [drawing a line with his finger on the screen] (inaudible) [00:22:24.21]



[He was drawing a line horizontally, not perpendicularly to the tilted axis.]

S35: This little thing right there could be it. How is that closer? [00:22:38.27]

S: C is not on the equator. [00:22:45.17]

S35: Exactly, so it would go around like that. It could be in the middle of (inaudible). It goes more like that (inaudible). [00:22:49.04]

S27 and S35 were arguing between C and D for the hottest place. S35 argued that it should be both C and D because both places were apart but the same distance from the equator. On the other hand, S27 argued that it was C because D was in the Southern Hemisphere, which was facing away from the sun. S27 also added that C was closer to something, but it was not clear what he meant by being closer. I want to note that the students drew an equator line horizontally (perpendicular to the day-night line) not perpendicularly to the tilted axis. This same misconception was found in another class. In the later of the discussion, the teacher corrected it as below.

> T: Ok, before you continue any farther, I just want to make you aware of one thing. Look up here for a minute and I'm going to show you on the globe. I noticed that a lot of people are looking at one point and you're going from that point straight across, or from this point straight across, or this point straight across. If you look at the globe, it's tilted, so take a look at the equator for example. It doesn't go from this point straight across, it goes on an angle because it's tilted. [00:24:22.14]

She also let the students know that the equator is placed between C and D.

> T: The equator would be on this one, so it would be between C and D. [00:27:34.20]

The student argument in the small group was continued as below.

> S27: A, B, and C are facing more towards the sun, and D, E, and F are facing more away. [00:31:30.25]
>
> S35: so C and D. [00:31:39.22]
>
> S: C and D.
>
> S30: yeah.
>
> S: Like I said before, this doesn't make sense.
>
> S30: Actually, no. [looking at the screen] I see C and D because look at, they are like B and D are basically like the same thing, right? Basically the same spot. [00:31:44.20]

The group members agreed with S35 that both C and D were the hottest places. Then S27 looked for a material to aid his explanation and found a flashlight and a globe as below.

S: What are you doing S27?

S34: What are you trying to prove? It's C and D! [00:39:26.25]

S27: No, (inaudible)

S34: S27, why C?

S27: Because it is close to the equator.

Now, it is clear that S27 thought that C was the hottest place because it was *close to the equator*. Their conversation continued.

S34: What is it matter?

S30: He thinks it is C because it is (inaudible). [00:39:46.28]

S34: They have to be equal.

S35: It's C and D! S27, let me see. [grab the globe and the flashlight from S27] [00:40:09.24] So you're spinning it like that...If you look at it, it's like a million light-years away. [Walking to the other side of class with a flashlight] [S27: It's not million light-years] whatever. S30, Look, look at it from right here, ok? So, now the sun...(unclear)

S35: Alright good enough. So when it is facing like that, it's both C and D, so (pause). It's both C and D because (pause), I can't explain it now! [00:40:43.24]

…..

[Now the students in this group all moved up to the front to the computer, and moved a mouse, looking at the photo on screen]

[S25, S35 & S30 then moved up to the screen and pointing at the photographs] [00:42:22.01]

[S25 is holding a ruler on the screen and S35 is talking]

S35: [pointing at the screen] The imaginary line could be [00:42:22.18]

S30: (simultaneously) [drawing an equator line with his finger on the screen]

S27: [from the monitor] The equator is right here. [moving the computer mouse and pointing it on the computer screen] S35, it's not over there.

S35: [pointing at a point on screen] the equator is in the middle of right here. [drawing an equator line with his finger] See, this is, S27. [00:42:34.14]

S27: Where is the rotational axis?

S: Yes it is!

S27: [coming to the screen] that's the distance from the north pole to the south pole. (inaudible) [00:42:53.04]

S35: [measuring a distance with the ruler]

[S27 and S30 went back to the computer] [00:43:10.08]

The students in this group went to the front and measured each distance of C and D from the equator line. They simply thought that *the place that was closest from the equator line was the hottest place*, but did not reason why the equator would have high temperature on earth. No one mentioned in this group the angle of the surface that receives the sunlight.

Similar episode happened in the intervention class 1 on day 16. The students in this class previously had a small group discussion about the question and then were presenting each group's thought.

T: So, I'm just going to pick different groups and if anyone would like to speak about that question, they can. So let's look at number 1A. What do you think is the hottest place among the places, A, B, C, D, E, and F, and why. [00:37:34.12]

S12: I think it's C, *because it's closer to the equator, and the equator's a hot spot.*

T: Okay, closest to the equator, and what was the last thing you said?

S12: the hottest spot.

T: It's the hottest area on earth? So you think it's C? Okay, S3, how about your group?

S3: I think it's C *because it's closer to the equator* <u>and it has direct sun. Well it's the (inaudible). It would be the closest to the direct, ahm. It's not direct, but it's close to direct.</u>

T: Okay, the rays that hit at point C are much more direct than at A, B, or D, E or F? Is that what you're saying? Okay. Okay, S9?

S9: We chose D, *because it's below the equator, which is the hottest point,* and because the sunlight is directly hitting D, you can see in the picture, closest, there's like this big blob of light and D is in the middle of it. C is getting a little of it, (inaudible)

T: Okay. How about this group, S13, what did your group have think about that question?

S13: I think <u>it's C because it gets the most direct sunlight</u>.

T: Okay, so we had, two groups, three groups thinking C, and two groups said because it receives the most direct sunlight, and another group said it was because it was closest to the equator. This group said D saying it was, you said that was closest to the equator and where it appears to be the most, the brightest spot where the sun is hitting? Uh, did anyone look at the globe up here? What don't people think about what this group said? And I want this group to think about what the other groups said. Have anything? Anyone like to respond. Because three groups disagree with this group. This group disagrees with three groups here. S8, what do you want to say?

S8: Can I go up to the board?

T: Yes, you can. I need everybody looking up here.

S8: They said that D was the hottest place, because this is the equator, and the axis is right here, [indicating the axis on the north pole area] so um, the equator would go straight across [drawing a flat line from C], like where C was, it would be like it would probably be like an angle [drawing an angled line vertical to the axis] go like right there between B and D, when C and up to A is all in the summer, and A has um white night. Usually summer has warmer temperatures than winter, and polar darkness usually happens in winter.

T: Okay. Anyone else? Okay. S6.

S6: [he also goes to the front of the class, to the slide] Because the equator is um like a straight line [drawing an angled line from D vertical to the axis] and the sun

> is over here [pointing the right side of the earth], the most direct would be towards C, and less direct sun would be towards D [pointing D].[00:42:37.13]

In the early of the discussion, S12 and S3 said that the hottest place was *C because it was closest to the equator*. Although S3 mentioned <u>direct sun,</u> he still held the conception that C was the hottest *because it was the closest to the equator* where it receives the most direct sunlight, not that C was the place that received the most direct sunlight. In the later of the discussion, some students, such as S13, S8 and S6, started to mention that C was the hottest because it received the most direct sunlight.

Summary

I listed several misconceptions found from the student conception survey and the classroom observations. In the questions about reasons for day-night and seasonal changes, the students often simply described the phenomena with what they had experienced, rather than giving scientific explanations about *why* the phenomena happened. Common patterns in their responses were relating the sun with daytime and summer, and relating the moon with nighttime and winter. It may have come from their preconceptions that the sun is bright and hot and that the moon is dark and cold. Another strong misconception was about the distance between the sun and the earth for the reason for the seasonal change on earth. Although the concept of the tilted rotational axis was understood, some students still held the misconception about the distance and thought that the earth was closer to the sun because it was tilted toward, and the earth was further from the sun because it was tilted away.

3. Pre- and Post-Conception Survey Results

In this section, I describe the rubrics and student performance on the pre- and post-tests. The test scores are reported with tables in this section. Statistical tests were conducted to measure whether there was a significant gain between the pre- and the post-tests for each class and whether there was a significant difference on the means of the knowledge gains between the intervention group and the traditional group. To check the former one, *repeated-measures t-test* was conducted. To check the latter one, *independent samples t-test* was conducted. Due to small sample sizes, their normal distributions were checked using *q-q plots* and the *Shapiro-Wilk Test*. Test results indicate that the mean of the knowledge gains in the intervention group is significantly different from the mean of the knowledge gains in the traditional group.

Rubrics

The conception survey questions were all open-ended. Therefore, certain guidelines were needed to examine student responses on the tests. The below are the rubrics that were used for each conception survey question.

Survey question 1: What is your definition of 'day (daytime)' and 'night (nighttime)'?

Rubric: [3]

	Primitive response	Non-scientific explanation	Partially correct but not enough scientific explanation	Scientifically correct explanation
Day [1.5]	0	0.5	1	1.5
Night [1.5]	0	0.5	1	1.5

The primitive response is the case of very naïve conception. The first notion that was introduced in the section of *student ideas about the concept of day-night* (p. 81) is the case. For example, code 0 was given for the response that day is when people are awake and night is when people go to sleep.

Code 0.5 was given when the students simply described brightness/darkness or gave a non-scientific explanation. Such examples are: day is light out, night is dark out, or night is when the moon is up, etc.

Code 1 is for a response that is partially correct but with explanation that is not scientific enough. Such examples are: day is when the sun is up in the sky, or night is when the sun is down.

Code 1.5 is for a response that provides scientifically correct explanation. For example, day happens on the side of which the earth faces the sun and night happens on the other side of the earth that faces away from the sun.

Survey question 2: Why do you think day and night happen on Earth?

Rubric: [3]

0	Primitive response
1	Non-scientific explanation: at least mention the sun or the earth
2	Partially correct but not enough scientific explanation
3	Scientifically fully correct explanation Mention both; i. the earth's rotation (or spin) and ii. explanation that day is when the earth *faces* the sun and night is when the earth *faces away* from the sun, or drawing a correct diagram

The primitive response (code 0) is the case of very naïve conception. Such an example is that day and night happen because there is time for people to go to bed and for people to enjoy the day.

Code 1 was given when explanation was non-scientific but at least the *sun* or the *earth* was mentioned. Such an example is that day and night happen because the earth revolves around the sun.

Code 2 was given when explanation was partially correct but needed more information to make it fully scientific. For example, students may have mentioned the earth's spin or rotation but did not give further explanation. They may have mentioned that day is when the earth faces the sun and night is when the earth faces away from the sun, but did not explain that the *earth's rotation* is the reason why day and night occur. Or, they may have simply drawn a diagram representing day and night but failed to provide further explanations.

Code 3 was given when students gave scientifically correct and ample explanation. Students mentioned the earth's rotation for the reason for day and night, and explained correctly that day is when the earth faces the sun and night is when the earth faces away from the sun (or provided a diagram that was drawn scientifically correct).

Survey question 3: Do you think different places on the earth have different lengths of daytime? Why or why not?

Rubric: [2]

	0	0.5	1
Change [1]	No	-	Yes
Reason [1]	Wrong	Partially correct	Correct

The survey question 3 asks two sub questions: i) whether or not you think different places on earth have different lengths of daytime, and ii) describe why or why not you think so. The correct answer for the first sub question is that different places on the earth have different lengths of daytime. Therefore code 1 was given when students responded that it differs (‘Yes’), and code 0 was given when they responded that it is the same (‘No’).

For the second sub question, code 0 was given when the response was non-scientific. Code 0.5 was given when the explanation was partially correct or when the students described a correct example for the different lengths of daytime at different places (for example, the North Pole has 6 months of darkness) without further explanation. Code 1 was given when students explained the reason scientifically correctly by mentioning the earth’s *tilted rotational axis*. The scientific explanation is that it happens (different places on earth have different length of daytime) because of the earth’s tilted rotational axis. The part on earth that is tilted toward the sun receives a longer length of sunlight (which is longer daytime on earth), and the part on earth that is tilted away from the sun receives shorter length of sunlight (which is shorter daytime on earth).

Survey question 4: How does the time of sunrise and sunset change throughout the year in XXX (northeastern US), and why?

Rubric: [2]

	Wrong	Partially correct	Correct
Description of sunrise & sunset [1]	0	0.5	1
Reason [1]	0	0.5	1

The survey question 4 also includes two sub questions: i) describe the time of sunrise and sunset changing throughout the year, and ii) explain why it happens. In the northeastern US, the sun rises earlier and sets later in summer, and the sun rises later and sets earlier in winter. Therefore, we have longer daytime in summer and shorter daytime in winter. When students correctly described it as above, code 1 was given. However, when student description was partially correct, but with either not enough information or wrong information, code 0.5 was given. When students simply wrote that daytime is longer in summer and shorter in winter, code 0.5 was also given. Code 0 was given when the response was wrong, or when they simply wrote “yes it changes” without describing *how* it changes.

The second sub question asks to explain *why* it changes throughout the year. Code 1 was given for a response that it happens because of the earth’s *tilted* rotational axis while it revolves around the sun throughout the year. If they mentioned the earth’s rotational axis but failed to mention ‘*tilted*’, code 0.5 was given. Code 0 was given when the response was wrong. An example for code 0 is that “it happens because of different seasons”.

Survey question 5: What do you think causes the seasons?

Rubric: [4]

0	Primitive response For example, weather, climate, the sun gets bigger or smaller, etc.
1	Non-scientific explanation at least mention the earth For example, - the earth moves around the sun (different distance between the sun and earth) - mention *revolution of the earth* without saying about *axis*
2	Partially correct but not enough scientific explanation (or showing partially wrong reasoning) For example, - mention only *axis* without saying *tilted* - mention *axis* as well as *revolution of the earth around the sun* - although mention *tilted axis* there is no further explanation, in addition there is no evidence that the student understands *how* tilted axis causes seasons on earth in his(her) diagram - may just write a simple fact without any further explanation
3	Scientifically correct explanation Should mention the earth's tilted rotational axis with scientifically correct explanation.
4	In addition to code 3, there is additional explanation by mentioning one of the reasons below. i. direct (more) / indirect sunlight (or different amount of sunlight) ii. different angle between the sunlight and the earth surface iii. different length of daytime

Student responses to the questions 5 and 6 revealed various misconceptions about the reason for seasons on earth. Among them, code 0 was given to naïve conceptions, for example, "it happens because of weather, the sun, or the moon, etc."

Code 1 was given when at least *the earth* was mentioned. Such cases include, "it happens because the earth moves around the sun," or "it happens due to different distance between the sun and the earth." But, the response in this category did not mention the earth's *axis*.

When students mentioned the earth's rotational axis without saying *tilted,* code 2 was given. This category included when there was no further explanation or there was no evidence showing that the student understood how a tilted axis causes the seasons on earth although they mentioned the earth's *tilted rotational axis*. When students simply wrote, "it happens because of the earth's tilted axis," without any further information, it was considered to be code 2.

Code 3 was given when students mentioned the *earth's tilted rotational axis* and gave sound reasoning. The responses in this category correctly described that "the hemisphere that is tilted toward the sun is summer and the other hemisphere that is tilted away from the sun is winter."

Code 4 was given when students provided additional explanation, in addition to what was written in code 3, by giving one of these reasons: 1) When it is tilted toward the sun, it receives more direct sunlight, and when it is tilted away from the sun, it receives indirect sunlight (receiving a different amount of sunlight due to the earth's tilted rotational axis), and that affects seasons on earth. 2) The amount of sunlight differs due to the different angle that the earth surface receives the sunlight, which affects seasons on earth. 3) The length of daytime differs due to the tilted rotational axis, affecting seasons on earth.

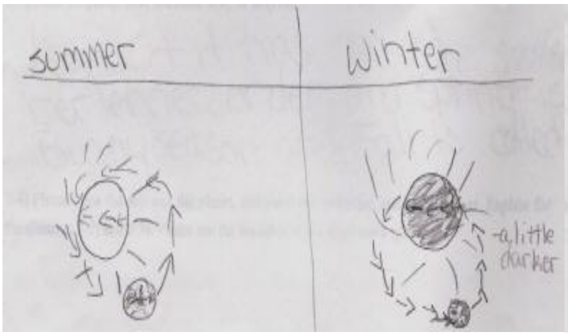
Survey question 6: Please draw the earth and the sun for summer and winter. Explain the causes of the seasons with your drawing.

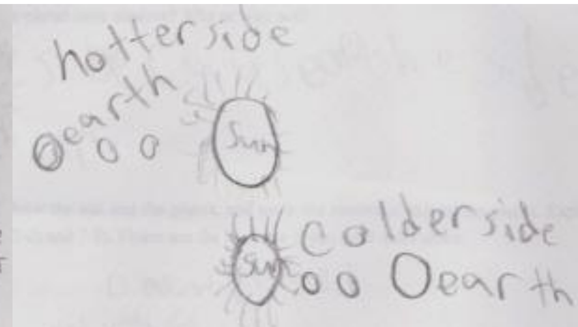
Rubric: [3]

0	Primitive diagram Showing very naïve conception For example, the diagram represents the earth that is divided into four areas having four different seasons for each; that the sun revolves around the earth; or the concept of day-night was drawn to explain the concept of seasons, etc.
1	Basic diagram i. Drawing of the earth and its orbit that revolves around the sun. ii. Note that summer and winter at the opposite positions of the orbit 0.5: Although the earth is drawn to revolve around the sun, its orbit has different shape or the size of the orbit is different for different seasons.
2	Partially correct but not enough information It should include: i. the earth's axis that is drawn tilted to its orbit around the sun ii. the same direction of the tilted axis for both June and December positions of the orbit Students in this code also show some flaws in their diagrams such as only one season was denoted on earth (not two different seasons for the Northern and the Southern Hemisphere). 1.5: When the direction of the tilted axis is drawn differently for both positions
3	Scientifically correct diagram In addition to the two standards of code 2, it should also include the below two conditions; i. understands that seasons are reversed in the Northern and the Southern Hemispheres, and ii. seasons are correctly indicated for both hemispheres 2.5: When the notes for seasons in the diagram correctly indicated different seasons on the Northern and the Southern Hemispheres at one position, but the other position was not drawn or given incorrect notes. Or, when an explanation was correctly given for the Northern Hemisphere but explanation for the Southern Hemisphere was missing.

Code 0 was given when student diagrams were primitive: for example, when the drawing represented trees for summer and snow for winter; the earth divided into four areas having four different seasons; the sun revolving around the earth; or when the day-night concept was explained for the seasonal change, etc.

Code 0 examples:

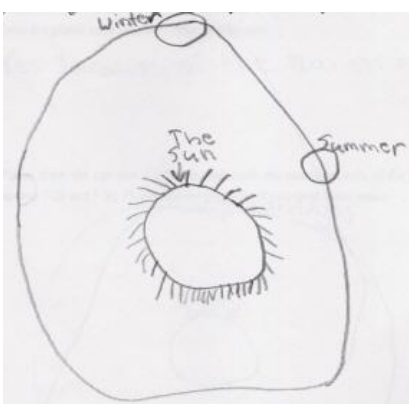


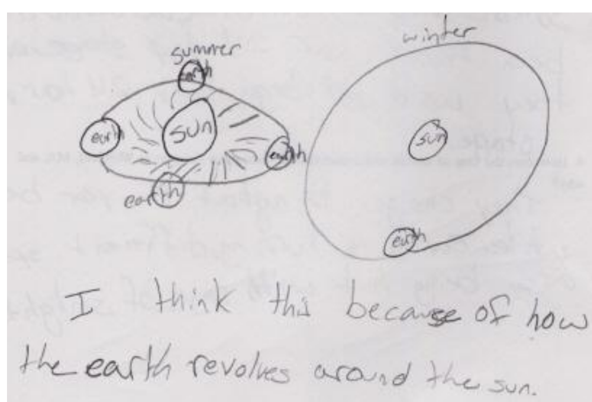


(Int1, S7, pre) (Int1, S10, pre)

Code 1 was given when student diagrams represented at least a basic concept of the earth's orbit around the sun although its explanation for the reason for the season was not scientifically correct. Such diagrams included the notes of *summer* and *winter* at the opposite positions of the orbit. However, when the notes were not at opposite positions or when the diagram represented two separate orbits for summer and winter, code 0.5 was given.

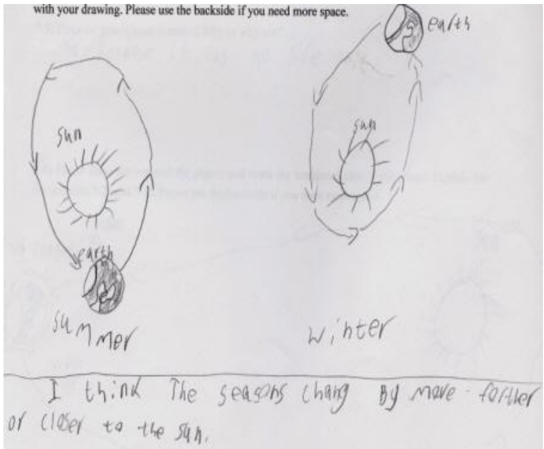
Code 0.5 examples:



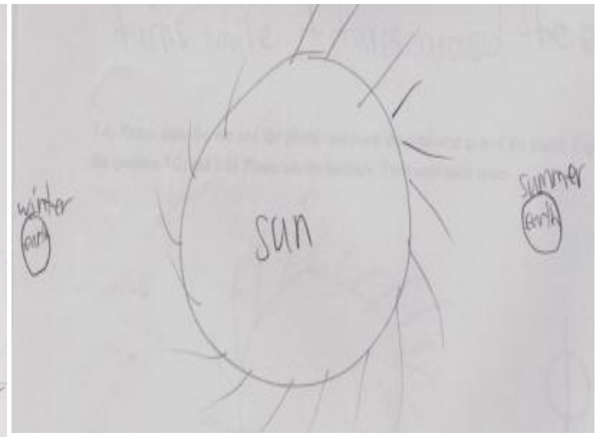


(Int2, S22, pre) (Int2, S35, post)

Code 1 examples:



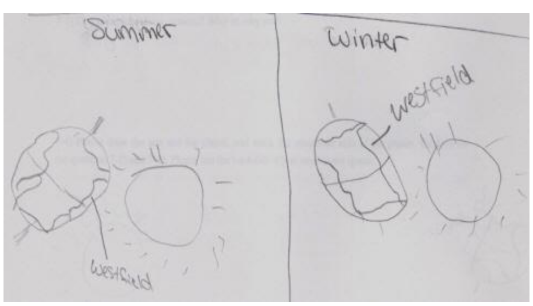
(Int1, S16, pre)



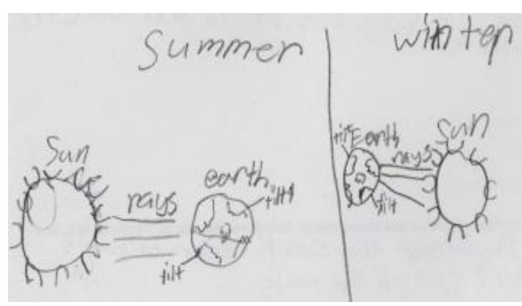
(Int1, S12, pre)

Code 2 was given when a diagram’s representation was partially correct but did not have enough scientific information. Such diagrams should include the *earth’s axis* drawn *tilted* to its orbit around the sun and the direction of the tilt should be the same for both June and December positions of the orbit. However, the diagram in this code may denote only one season on earth, not two different seasons for the Northern and the Southern Hemispheres, or the notes for seasons on the hemispheres were incorrect. When the direction of the tilted axis was drawn differently for both positions, code 1.5 was given.

Code 1.5 examples:

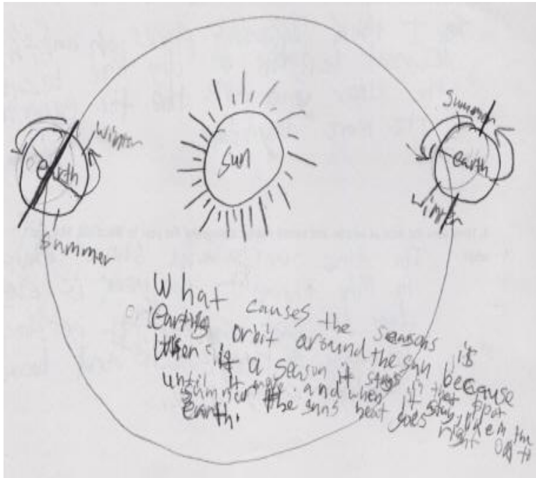


(Int2, S38, pre)

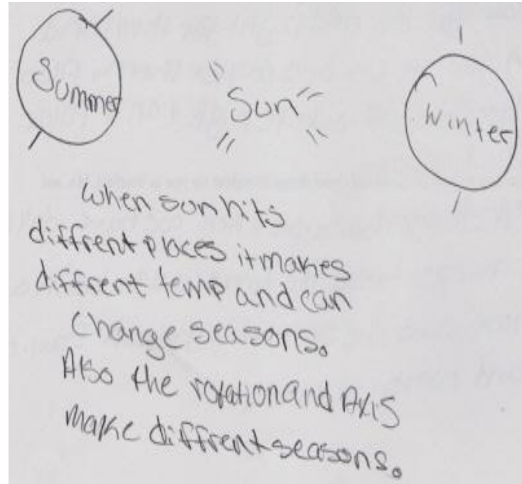


(Int1, S15, post)

Code 2 examples:



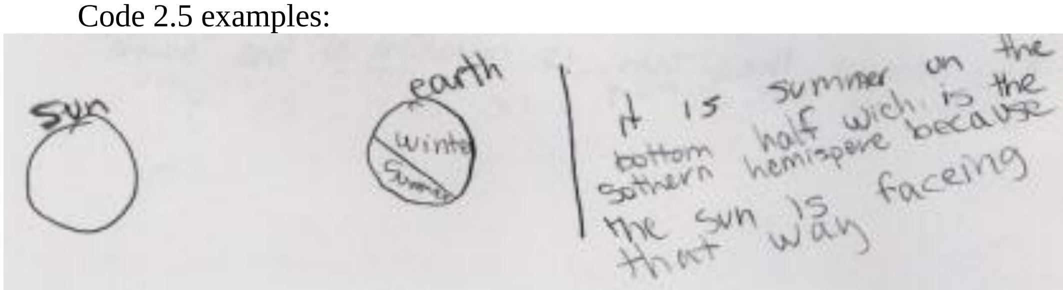
(Int1, S18, post): Seasons on the Northern & the Southern Hemispheres were written in a wrong way.



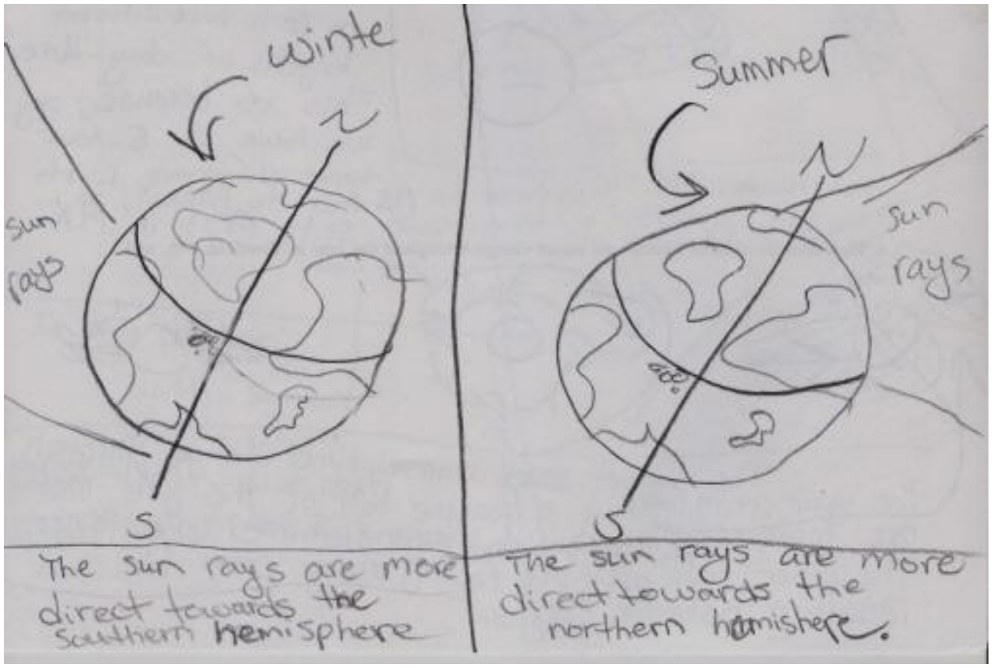
(Int1, S5, post): It is not clear if the season written on earth indicates for the Northern Hemisphere or for the whole earth.

Code 3 was given when the diagram correctly represented seasons at both the Northern and the Southern Hemispheres at both positions of the orbit. If the notes about seasons in the diagram correctly indicated different seasons on the Northern and the Southern Hemispheres at one position, but an explanation for the other position was not given, code 2.5 was given. When the explanation was correctly given for the Northern Hemisphere but an explanation for the Southern Hemisphere was missing, code 2.5 was given although its explanation for the season was scientifically correct.

Code 2.5 examples:

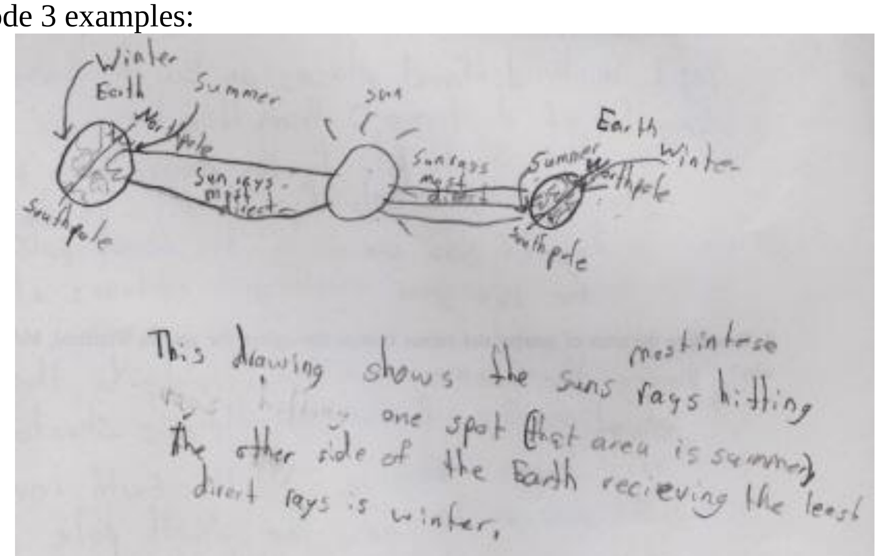


(Trad1, S51, post): Its explanation and notes about season were correct for the Northern and the Southern Hemispheres at one position, but there was no information about the other position.

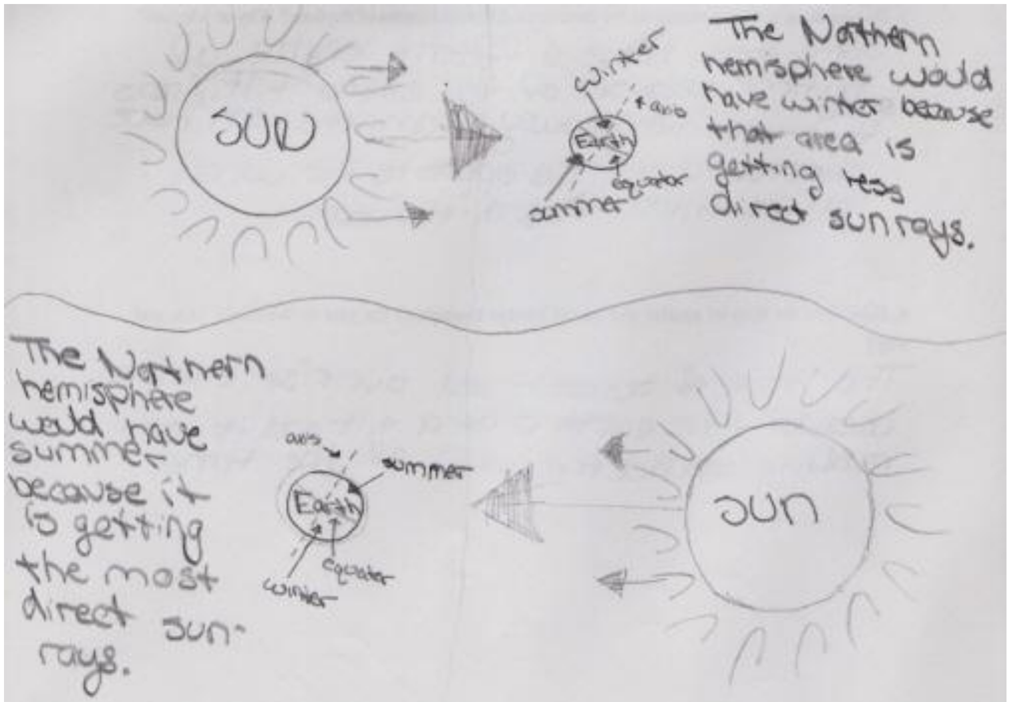


(Int1, S8, post): Explanation and the notes about seasons for the Northern Hemisphere were correct. But, there was no information about seasons for the Southern Hemisphere.

Code 3 examples:



(Int1, S1, post): The notes about seasons for both the Northern and the Southern Hemispheres at both positions were correctly described.



(Int1, S6, post): The notes about seasons for both the Northern and the Southern Hemispheres at both positions were correctly described.

Results

So far, I described rubrics for each conception survey question. In this section, I report the student performance on the pre- and post-conception surveys. Table 9 presents the number of students for each code for each survey question at each intervention and traditional class. Each class size was 18 for the two intervention classes, 19 for one traditional class, and 20 for two traditional classes. One or two students missed the test at some classes. Table 10 summarizes total number of students and its percentage for the intervention group and the traditional group for the pre- and the post-tests.

Table 9. The number of students for each code for each conception survey question at the pre/post-tests at each intervention (Int) and traditional (Trad) class

Question	Code	Number of Students									
		Int1 Pre n=18	Int1 Post n=18	Int2 Pre n=17	Int2 Post n=18	Trad1 Pre n=18	Trad1 Post n=19	Trad2 Pre n=20	Trad2 Post n=18	Trad 3 Pre n=20	Trad 3 Post n=20
Q1-day											
Primitive response	(0)	3	1	5	2	3	2	1	3	2	1
Non-scientific	(0.5)	6	3	0	4	4	5	6	4	3	2
Partial understanding	(1)	6	7	9	4	8	7	9	6	10	11
Scientifically correct	(1.5)	3	7	3	8	3	5	4	5	5	6
Q1-night											
Primitive response	(0)	3	1	4	3	4	2	2	4	3	2
Non-scientific	(0.5)	7	8	6	6	11	12	12	6	7	7
Partial understanding	(1)	4	2	4	3	2	2	4	2	6	6
Scientifically correct	(1.5)	4	7	3	6	1	3	2	6	4	5
Q2											
Primitive response	(0)	9	0	5	1	7	5	6	3	9	4
Non-scientific	(1)	2	2	3	1	2	4	2	0	2	1
Partial understanding	(2)	3	9	5	8	3	6	5	11	5	11
Scientifically correct	(3)	4	7	4	8	6	4	7	4	4	4
Q3-change											
No (wrong)	(0)	5	2	6	4	4	5	7	3	6	3
Yes (correct)	(1)	13	16	11	14	14	14	13	15	14	17
Q3-reason											
Wrong	(0)	16	6	15	11	14	14	18	12	18	15
Partial	(0.5)	0	7	1	5	3	3	1	2	2	3
Correct	(1)	2	5	1	2	1	2	1	4	0	2
Q4-description											
Wrong	(0)	18	10	14	8	13	15	14	12	17	17
Partial	(0.5)	0	5	1	5	3	2	3	2	3	3
Correct	(1)	0	3	2	5	2	2	3	4	0	0
Q4-reason											
Wrong	(0)	16	12	16	8	18	16	19	14	18	14

Partial	(0.5)	1	3	1	4	0	2	1	0	1	5
Correct	(1)	1	3	0	6	0	1	0	4	1	1
Q5											
Primitive response	(0 or 0.5)	13	0	10	1	10	4	15	3	11	6
Non-scientific	(1 or 1.5)	4	4	5	2	7	5	1	2	7	5
Partial understanding	(2 or 2.5)	1	4	1	6	0	6	4	7	0	5
Scientifically correct	(3)	0	6	0	5	0	3	0	5	0	4
Scientifically correct with additional explanation	(4)	0	4	1	3	0	1	0	1	0	0
Q6											
Primitive diagram	(0 or 0.5)	12	1	15	5	13	9	18	11	16	12
Basic diagram	(1 or 1.5)	4	5	2	1	3	3	2	1	2	2
Partial correct	(2 or 2.5)	2	7	0	4	1	3	0	4	0	0
Scientifically correct	(3)	0	5	0	7	0	4	0	2	0	2
Mean value		4.33	10.81	4.74	10.11	4.61	7.11	4.88	8.08	4.28	6.93

For the question about the definition of day and night (Q1), some students still gave primitive responses in the post-test, and the percentage was slightly higher at the traditional (day-10.53%, night-14.04%) than at the intervention group (day-8.33%, night-11.11%). At both intervention and traditional groups, students provided more primitive and non-scientific responses for the definition of night than for the definition of day in the post-test. The percentage of students who provided primitive and non-scientific responses was 27.77% at the intervention group and 29.83% at the traditional group for the definition of day, but 50.00% at the intervention group and 57.90% at the traditional group for the definition of night. This may have been occurred because many students were unable to relate the absence of the sun to the definition of night. They tended to

Table 10. Total number of students and its percentage for each code for each conception survey question at the prer/post-tests at the intervention group and the traditional group

Question	Code	Intervention (Int 1 & 2) Pre n=35		Intervention (Int 1 & 2) Post n=36		Traditional (Trad 1, 2, & 3) Pre n=58		Traditional (Trad 1, 2, & 3) Post n=57	
		Total #	%	Total #	%	Total #	%	Total #	%
Q1-day									
Primitive response	(0)	8	*22.86*	3	*8.33*	6	*10.34*	6	*10.53*
Non-scientific	(0.5)	6	*17.14*	7	*19.44*	13	*22.41*	11	*19.30*
Partial understanding	(1)	15	*42.86*	11	*30.56*	27	*46.55*	24	*42.11*
Scientifically correct	(1.5)	6	*17.14*	15	*41.67*	12	*20.69*	16	*28.07*
Q1-night									
Primitive response	(0)	7	*20.00*	4	*11.11*	9	*15.52*	8	*14.04*
Non-scientific	(0.5)	13	*37.14*	14	*38.89*	30	*51.72*	25	*43.86*
Partial understanding	(1)	8	*22.86*	5	*13.89*	12	*20.69*	10	*17.54*
Scientifically correct	(1.5)	7	*20.00*	13	*36.11*	7	*12.07*	14	*24.56*
Q2									
Primitive response	(0)	14	*40.00*	1	*2.78*	22	*37.93*	12	*21.05*
Non-scientific	(1)	5	*14.29*	3	*8.33*	6	*10.34*	5	*8.77*
Partial understanding	(2)	8	*22.86*	17	*47.22*	13	*22.41*	28	*49.12*
Scientifically correct	(3)	8	*22.86*	15	*41.67*	17	*29.31*	12	*21.05*
Q3-change									
No (wrong)	(0)	11	*31.43*	6	*16.67*	17	*29.31*	11	*19.30*
Yes (correct)	(1)	24	*68.57*	30	*83.33*	41	*70.69*	46	*80.70*
Q3-reason									
Wrong	(0)	31	*88.57*	17	*47.22*	50	*86.21*	41	*71.93*
Partial	(0.5)	1	*2.86*	12	*33.33*	6	*10.34*	8	*14.04*
Correct	(1)	3	*8.57*	7	*19.44*	2	*3.45*	8	*14.04*
Q4-description									
Wrong	(0)	32	*91.43*	18	*50.00*	44	*75.86*	44	*77.19*
Partial	(0.5)	1	*2.86*	10	*27.78*	9	*15.52*	7	*12.28*
Correct	(1)	2	*5.71*	8	*22.22*	5	*8.62*	6	*10.53*
Q4-reason									
Wrong	(0)	32	*91.43*	20	*55.56*	55	*94.83*	44	*77.19*
Partial	(0.5)	2	*5.71*	7	*19.44*	2	*3.45*	7	*12.28*
Correct	(1)	1	*2.86*	9	*25.00*	1	*1.72*	6	*10.53*
Q5									
Primitive response	(0 or 0.5)	23	*65.71*	1	*2.86*	36	*65.45*	13	*22.81*
Non-scientific	(1 or 1.5)	9	*25.71*	6	*17.14*	15	*27.27*	12	*21.05*

Partial understanding	(2 or 2.5)	2	*5.71*	10	*28.57*	4	*7.27*	18	*31.58*
Scientifically correct	(3)	0	*0.00*	11	*31.43*	0	*0.00*	12	*21.05*
Scientifically correct with additional explanation	(4)	1	*2.86*	7	*20.00*	0	*0.00*	2	*3.51*
Q6									
Primitive diagram	(0 or 0.5)	27	*77.14*	6	*17.14*	47	*85.45*	32	*60.38*
Basic diagram	(1 or 1.5)	6	*17.14*	6	*17.14*	7	*12.73*	6	*11.32*
Partial correct	(2 or 2.5)	2	*5.71*	11	*31.43*	1	*1.82*	7	*13.21*
Scientifically correct	(3)	0	*0.00*	12	*34.29*	0	*0.00*	8	*15.09*

think that the moon or darkness was the reason for night. On the other hand, they were easily able to relate the sun to the definition of day.

In the survey question 2, which asked about the reason for day-night, there was a large difference on the student responses between the intervention and the traditional group. In the pre-test, the percentage of students who provided primitive response was similar between the intervention (40.00%) and the traditional (37.93%) group. However, in the post-test, only 2.78% provided primitive responses at the intervention group while 21.05% at the traditional group. In addition, the percentage of students who provided scientifically correct explanation at the intervention group (41.67%) was almost twice as many at the traditional group (21.05%).

Survey question 3 asked about the length of daytime at different places on earth. Although most students at both intervention (83.33%) and traditional groups (80.70%) correctly thought that it would differ depending on places, many of them could not explain the reason why it happens scientifically correctly: 47.22% at the intervention group and 71.93% at the traditional group still provided wrong reasoning in the post-test. The percentage of students who gave scientifically correct explanation was slightly higher at the intervention group (19.44%) than at the traditional group (14.04%) in the post-test. The percentage of students who showed partial scientific understanding was significantly higher at the intervention group (33.33%) than at the traditional group (14.04%) in the post-test.

Survey question 4 consisted of two sub questions: one was to describe how the length of daytime changes throughout the year and the other one was to explain why it happens. In the pre-test, most students at both intervention and traditional groups provided wrong description (intervention group 91.43%, traditional group 75.86%) and wrong explanation (intervention group 91.43%, traditional group 94.83%). In the post-test, the percentage of students who provided wrong description and wrong explanation was still high for both intervention and traditional group, but it was somewhat higher at the traditional group (77.19% for description and 77.19% for reason) than at the intervention group (50.00% for description and 55.56% for reason). The percentages of students who gave correct description and correct explanation were higher at the intervention group (22.22% for description and 25.00% for reason) than at the traditional group (10.53% for description and 10.53% for reason). It is a bit disappointing that a high percentage of students, even at the intervention group (although the intervention group showed higher gain than the traditional group), still could not provide scientific explanation in the post-test about the reason for different length of daytime.

Survey question 5 asked about the reason for seasonal change on earth. In the pre-test, the percentage of students for each code was similar between the intervention and the traditional groups: 65.71% vs. 65.45% for primitive response, 25.71% vs. 27.27% for non-scientific explanation, 5.71% vs. 7.27% for partial understanding, 0.00% vs. 0.00%

for scientifically correct explanation, and 2.86% vs. 0.00% for scientifically correct with additional explanation. On the other hand, in the post-test, the percentage of students who provided primitive responses was much higher at the traditional group (22.81%) than at the intervention group (2.86%). The percentage of students in the post-test who provided scientifically correct explanation was higher at the intervention group (31.43%) than at the traditional group (21.05%), and more students were able to provide additional scientific explanation at the intervention group (20.00%) than at the traditional group (3.51%).

The last question asked the students to draw a diagram to explain the seasonal change on earth. In the pre-test, the percentage of students for each code was similar between the intervention and the traditional groups: 77.14% vs. 85.45% for a primitive diagram, 17.14% vs. 12.73% for a basic diagram, 5.71% vs. 1.82% for a partially correct diagram, and 0.00% vs. 0.00% for a scientifically correct diagram. On the other hand, in the post-test, the percentage of students who drew a primitive diagram was only 17.14% at the intervention group while it was over 60% at the traditional group. The percentage of students who were able to draw a scientifically correct diagram was higher at the intervention group (34.29%) than at the traditional group (15.09%).

In general, the students at the intervention group were outperformed than the students at the traditional group. Figure 12 represents the mean values of the pre- and post-conception survey results for each intervention and traditional class. As can be seen in the figure, the mean values are almost similar at five classes in the pre-test, which are in the range of between 4 and 5. But the post-test results show that the mean values are higher at the two intervention classes than at the three traditional classes. The exact mean values for each class for each test were noted at the last low in Table 9.

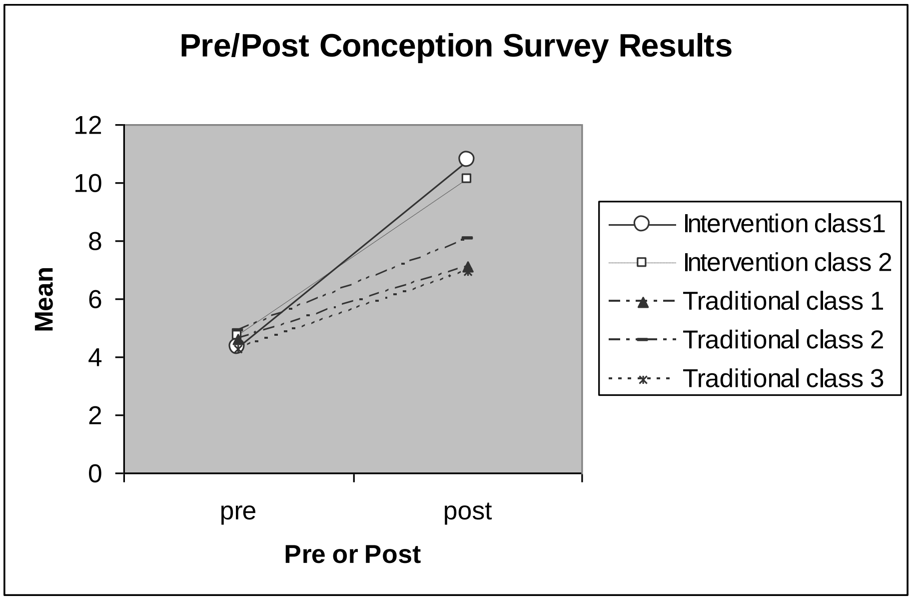


Figure 12: The mean values of the pre/post-conception survey results for each class

Statistical Tests

This section describes statistical test results that were conducted to examine i) whether there was a significant knowledge gain after the instruction for each class, and ii) whether there was a significant difference on the knowledge gains between the intervention group and the traditional group. The former one was conducted by comparing a post-test score with a pre-test score for each student for each class, which is called in *within group*. The latter one was conducted by comparing the knowledge gains of the intervention group with the knowledge gains of the traditional group, which is called *between group*. The former statistical method is called *dependent (or repeated-measures) t-test*, and the latter one is called *independent samples (or two-sample) t-test*.

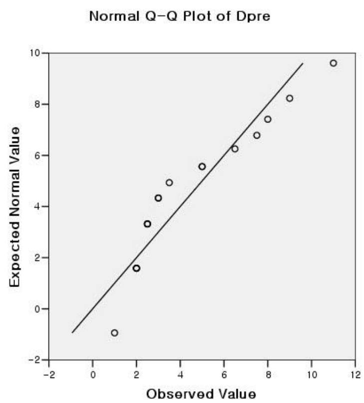
Repeated-Measures T-test

Repeated-measures t-test is also called *paired-samples t-test*. This test is performed to check if there is a significant difference in *within group* that has the same subjects. In this study, the repeated-measures t-test was used to understand if there was a significant difference on student knowledge gain between the pre-test and the post-test for each class. The repeated-measures t-test requires two basic assumptions (Gravetter & Wallnau, 2000, p.355):

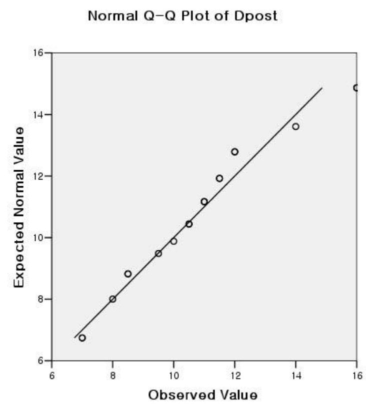
i) The observations within each treatment condition must be independent. Notice that the assumption of independence refers to the scores within each treatment. Inside each treatment, the scores are obtained from different individuals and should be independent of one another.

ii) The population distribution of differences scores must be normal.

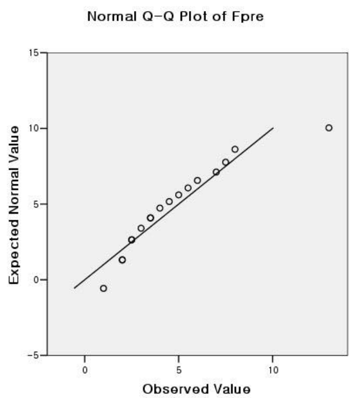
Because the pre-test and the post-test were performed independently and its scores were obtained from individual students at each test, it satisfies the first assumption. But the second assumption needs to be checked because each class size is small (less than 30). Normality can be easily checked with q-q plot. This is a scatterplot with the quantile of the scores (observed values) on the horizontal axis and the expected normal scores on the vertical axis. The plot of the scores against the expected normal scores should reveal a straight line. Figure 13 shows q-q plots of the pre-test and the post-test for each class. As can be seen in the figure, most plots reveal straight lines, except the ones of the intervention class 1 pre-test and the traditional class 1 post-test. They look to be deviated from the straight line.



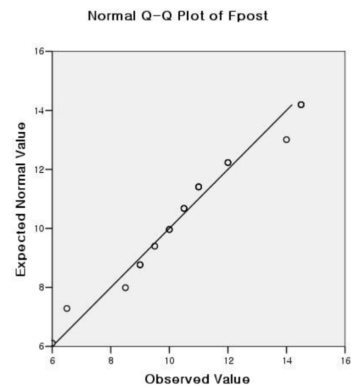
Intervention class1 pre-test



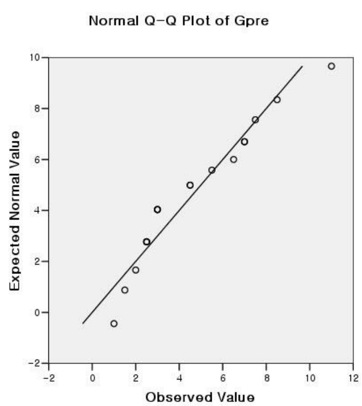
Intervention class1 post-test



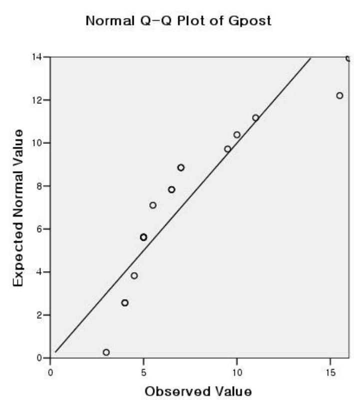
Intervention class2 pre-test



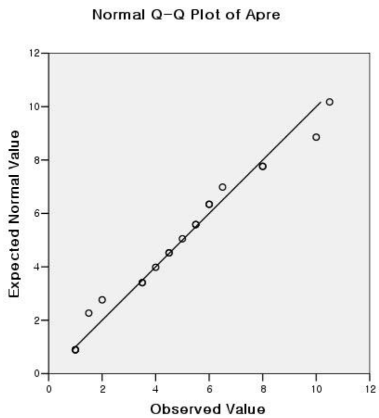
Intervention class2 post-test



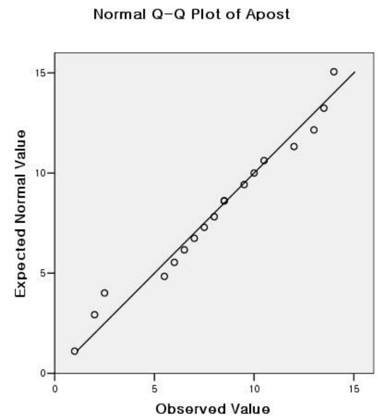
Traditional class1 pre-test



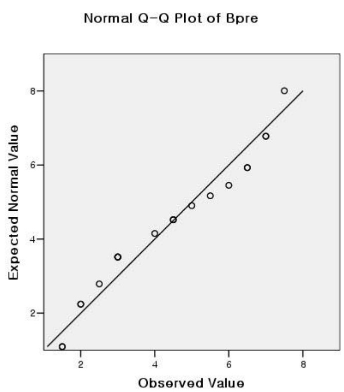
Traditional class1 post-test



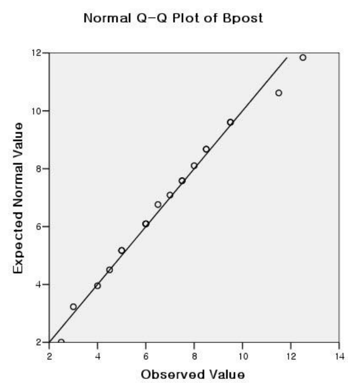
Traditional class2 pre-test



Traditional class2 post-test



Traditional class3 pre-test



Traditional class3 post-test

Figure 13: Q-Q plots of pre- and post-tests for each class

For detailed information about the normal distribution for each class for each test, the *Shapiro-Wilk Test* was conducted. This test assesses the normality of a distribution when sample size is smaller than 50. The null hypothesis is that the population is normally distributed. If its p-value is less than 0.05, the null hypothesis is rejected. When its p-value is greater than 0.05, the null hypothesis is not rejected, which indicates that the data is distributed normally. Table 11 shows the results of the Shapiro-Wilk Test using SPSS software (Analyze → Descriptive Statistics → Explore).

Table 11. Shapiro-Wilk Test results for each class for its pre/post-test

Class	Pre/post-test	Shapiro-Wilk		
		Statistics	Df	Sig.
Intervention 1	pre	.862	18	.013
	post	.937	18	.260
Intervention 2	pre	.894	17	.054
	post	.955	17	.534
Traditional 1	pre	.922	18	.140
	post	.816	19	.002
Traditional 2	pre	.948	20	.334
	post	.963	18	.660
Traditional 3	pre	.924	20	.121
	post	.979	20	.926

All the Shapiro-Wilk sig. values, except the ones of the intervention class 1 pre-test and the traditional class 1 post-test, are greater than 0.05, which indicates that they can be assumed to be the normality of the distribution. The pre-test of the intervention class 1 and the post-test of the traditional class 1 do not satisfy the assumption of the normal distribution. This result was expected from the q-q plots.

Table 12 shows the repeated-measures (paired samples) t-test results for pre- and post-test scores at each class and provides the summary of descriptive statistics. I want to note that the sum of *codes* of the test for each student is substituted to *score* that is a scale in the range of 0 to 1. In other words, if a student got 10 codes on the test based on the rubrics, his *score* on the test is 0.5888. This value was obtained by dividing 10 into 17, which is the maximum value if one gets all correct answers on the test. Similarly, if one got 5 codes out of 17 on the test, his *score* is 0.294. The null hypothesis of the test is;

Ho = the score mean of the pre-test and the score mean of the post-test for each class are not significantly different (the difference between the score means of the pre-test and the post-test is equal to 0), $\mu_{pre} = \mu_{post}$,

and the alternative hypothesis is;

Ha = the score mean of the pre-test and the score mean of the post-test for each class are significantly different (the difference between the score means of the pre-test and the post-test is not equal to 0). $\mu_{pre} \neq \mu_{post}$.

The test was performed with 99% confidence (α=0.01). In other words, when its p value is less than 0.01, the null hypothesis is rejected. For example, if the p value is 0.001, p (0.001) < α (0.01), the null hypothesis is rejected, and it is true to say that the mean score of the pre-test and the mean score of the post-test for the class is significantly different.

Table 12. Repeated-Measures T-test results (99% confidence)

Class	Pre/ post-Test	Paired Samples Statistics				Paired Differences			T-test		
		Score Mean	N	SD	SE	Mean differ-ence[1]	SD	SE	t	df	p (2-tailed)
Int1	pre	0.255	18	0.1703	0.0401	-0.381	0.1880	0.0443	-8.590	17	0.000
	post	0.636	18	0.1550	0.0365						
Int2	pre	0.279	17	0.1737	0.0421	-0.339	0.2199	0.0533	-6.359	16	0.000
	post	0.618	17	0.1437	0.0349						
Trad1	pre	0.258	17	0.1575	0.0382	-0.138	0.1386	0.0336	-4.116	16	0.001
	post	0.396	17	0.1918	0.0465						
Trad2	pre	0.301	18	0.1669	0.0393	-0.175	0.1683	0.0397	-4.406	17	0.000
	post	0.475	18	0.2252	0.0531						
Trad3	pre	0.251	20	0.1174	0.0263	-0.156	0.1826	0.0408	-3.818	19	0.001
	post	0.407	20	0.1548	0.0346						

[1]: (Mean difference) = (score mean of the pretest) – (score mean of the posttest)

As can be seen in Table 12, all five classes have p values that are less than 0.01. Because the intervention class 1 pre-test and the traditional class 1 post-test did not satisfy the assumption of the normal distribution, it is unclear whether the students in the intervention class 1 and in the traditional class 1 had a significant gain. However, it is true to say that the students in the intervention class 2, traditional class 2 and 3 had a significant gain after they had the instruction in each class. It is noticeable that the mean differences between the pre-test and the post-test at the intervention classes are larger than the ones at the traditional classes.

Independent Samples T-test

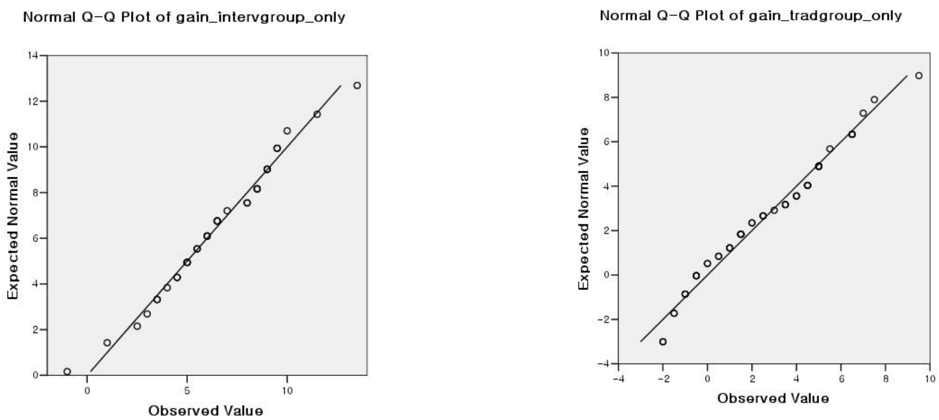
My next interest was to check whether there was a significant difference between the intervention group and the traditional group on student knowledge gains. The appropriate statistical method for this is *independent samples (or two-sample) t-test*. Independent samples t-test is widely used to compare the score means of two independent groups and to check if there is a significant difference in *between groups*. To perform independent samples t-test, the below three assumptions should be satisfied (Gravetter & Wallnau, 2000, p.328):

i) The observations within each sample must be independent.

ii) The two populations from which the samples are selected must be normal.

iii) The two populations from which the samples are selected must have equal variances.

The first assumption is satisfied because the test was performed in independent group. The second assumption can be checked for normal distribution with q-q plots. Figure 14 shows the q-q plots of pre-post score differences (knowledge gains) for the intervention group (2 classes) and the traditional group (3 classes), and Figure 15 shows the q-q plot of pre-post score differences for all five classes. As can be seen in the figures, they seem to reveal straight lines.



Intervention group (2 classes) Traditional group (3 classes)

Figure 14: Q-Q plots of the pre-post score differences (knowledge gains) for the intervention group and the traditional group

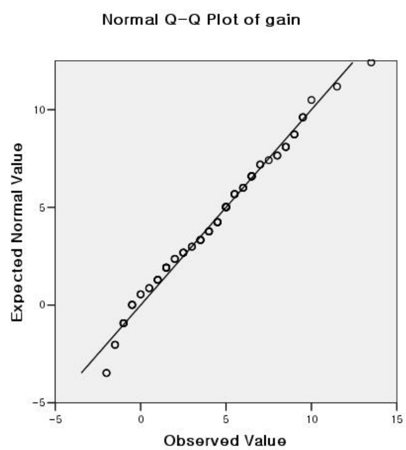


Figure 15: Q-Q plot of the pre-post score differences (knowledge gains) for all five classes (both intervention and traditional groups)

Again, to be much accurate, the Shapiro-Wilk Test was performed. The similar test to the Shapiro-Wilk is the *Kolmogorov-Smirnov Test* when the sample size is greater than 50. It also indicates the normality of the distribution when its sig. value is greater than 0.05. Table 13 shows the results of the Shapiro-Wilk and the Kolmogorov-Smirnov Test on the pre-post score differences for the intervention group (2 classes), the traditional group (3 classes), and both groups together (5 classes). As can be seen in the table, the data from the intervention group, the traditional group, and both groups together satisfy the second assumption, the normality of the distribution.

Table 13. Shapiro-Wilk Test and Kolmogorov-Smirnov Test results on the pre-post score differences for the intervention group (2 classes), the traditional group (3 classes) and both groups together (5 classes)

Post-test	Shapiro-Wilk [a]			Kolmogorov-Smirnov		
	Statistics	df	Sig.	Statistics	Df	Sig.
Intervention group (2 classes)	**.988**	**34**	**.963**	.083	34	.200
Traditional group (3 classes)	.969	55	.163	**.099**	**55**	**.200**
Both intervention and traditional groups together (5 classes)	.981	89	.202	**.071**	**89**	**.200**

[a] Shapiro-Wilk test is appropriate for the intervention group because its sample size is less than 50. The sample size for the traditional group or both groups together is larger than 50, so Kolmogorov-Smirnov test is appropriate.

Lastly, the third assumption can be checked with *Levene's Test*. The null hypothesis is that the population variances are equal. If its p-value is less than 0.05, the null hypothesis is rejected, which means that the two variances are significantly different. When its p-value is greater than 0.05, the null hypothesis is not rejected, which means that the two variances are approximately equal. In Table 14, p-value of the Levene’s Test is greater than 0.05; the Levene's Test is not significant. Therefore it satisfies the third assumption, the equality of the variances.

Table 14. Levenen's Test

	Pre-post score differences (knowledge gains)			Levene's Test for Equality of Variances	
	mean	SD	SE	F	Sig.
Intervention group	.3780	.17619	.03022	.002	.963
Traditional group	.1567	.16298	.02198		

Table 15 shows independent-samples t-test results on the pre-post score differences (knowledge gains) between the intervention group and the traditional group. In this test, the null hypothesis is;

Ho = the difference between the mean of knowledge gains in the intervention group and the mean of knowledge gains in the traditional group is equal to 0;

$\mu_{interventtion\text{-}knowledgegain} = \mu_{traditional\text{-}knowledgegain}$

and the alternative hypothesis is;

Ha = the difference between the mean of knowledge gains in the intervention group and the mean of knowledge gains in the traditional group is not equal to 0;

$\mu_{interventtion\text{-}knowledgegain} \neq \mu_{traditional\text{-}knowledgegain}$

Table 15. Independent Samples T-test on the knowledge gains between the intervention group and the traditional group (99% confidence)

Intervention group vs. Traditional group	Independent-Samples T-test				
	Mean difference	SE	t	df	p (2-tailed)
	.2213	.03667	6.035	87	.000

As can be seen in Table 15, its p value is less than 0.01, and the null hypothesis is rejected. Therefore, it is true to say that the mean of the knowledge gains (pre-post score differences) in the intervention group is significantly different from the mean of the knowledge gains (pre-post score differences) in the traditional group.

Summary

In this section, I reported the student performances on the pre- and post-conception survey. The student mean scores were similar in the pre-test between the intervention group and the traditional group. In the post-test, however, the students in the intervention group outperformed the students in the traditional group. Repeated-measures t-test, which was performed for within group, showed that the students in the intervention class 2, the traditional class 2, and the traditional class 3 had a significant gain after they had the instruction. Independent-samples t-test, which was performed for between groups, showed that the mean of the knowledge gains of the intervention group was significantly different from the one of the traditional group.

4. Student and Teacher Attitudes

In this section, I present the results from the student perception (attitudes) survey and the student short surveys that were performed in the two intervention classes, and the teacher interviews. The perception survey was performed when the whole unit was ended while the short surveys were infrequently performed at the end of a class while the lessons were taught. Teacher interviews were performed before starting and after finishing the whole lessons, as well as during the lessons.

First, I describe the student attitudes found from the perception survey and the short surveys. The perception survey consisted of Likert-type questions and open-ended questions. The student responses to the Likert-type questions are reported with descriptive statistics. The student responses to the open-ended questions of the perception survey and the short surveys are categorized into several themes. The results showed that the student's attitudes toward the lessons and learning with the photographs and CRSs were generally very positive.

Second, the teacher interviews show that the teacher encountered several difficulties while she was performing the classroom discussion with the new pedagogy. However, she thought that the lessons with the new pedagogy had a very positive impact on teaching and learning. At the end of the section, I provide the summary of the findings about the students and the teacher attitudes.

Student Attitudes toward the Lessons

Likert-type Questions Results

The Likert-type questions of the perception survey asked the students to choose their answers among the choices of strongly no, no, I don't know, yes or strongly yes. Table 16 shows the numbers of students who responded to each choice for each question. In general, the student responses were positive. It is important to note that the question 8 and the question 17 were asked in a negative way, and therefore the high number for the choice "strongly no" indicates a student positive attitude.

Table 16. The numbers of the student responses to the questions about their learning experience with the new lessons in the intervention classes
(Intervention class 1: n=18, Intervention class 2: n=16, total: n=34)

#	Questions	Number of students					
		class	Strongly No	No	I don't know	Yes	Strongly Yes
1	It was a lot of fun to use clickers in class.	Int1	0	0	1	2	15
		Int2	0	0	0	4	12
		Total	0	0	1	6	27
2	I hope my teacher keeps using the clickers.	Int1	0	0	0	6	12
		Int2	0	0	0	4	12
		Total	0	0	0	10	24
3	The use of clickers made me more interested in learning astronomy.	Int1	1	2	3	6	6
		Int2	0	2	0	11	3
		Total	1	4	3	17	9
4	I really liked to see the photographs in class.	Int1	0	0	2	8	8
		Int2	0	0	4	9	3
		Total	0	0	6	17	11
5	I hope my teacher keeps using photographs in astronomy class.	Int1	0	0	2	8	8
		Int2	0	0	2	8	6
		Total	0	0	4	16	14
6	The photographs made me more interested in learning astronomy.	Int1	1	3	3	5	6
		Int2	0	2	2	9	3
		Total	1	5	5	14	9
7	The photographs made me think a lot about astronomy concepts.	Int1	0	2	7	3	6
		Int2	0	0	2	8	6
		Total	0	2	9	11	12
8[a]	The photographs confused me about astronomy concepts.	Int1	10	6	1	0	1
		Int2	5	6	4	0	1
		Total	15	12	5	0	2
9	The photographs helped me to learn astronomy better.	Int1	0	1	3	7	7
		Int2	0	0	2	10	4
		Total	0	1	5	17	11
10	The photographs helped me to notice scientific phenomena around me.	Int1	0	0	5	8	5
		Int2	0	2	3	7	4
		Total	0	2	8	15	9
11	The photographs help me to learn different views about the concepts.	Int1	0	0	4	8	6
		Int2	0	0	2	14	0
		Total	0	0	6	22	6
12	I felt more involved in this class than my other classes.	Int1	2	3	3	7	3
		Int2	1	1	8	3	3
		Total	3	4	11	10	6

13	Seeing photographs helped me pay more attention in class.	Int1 Int2 Total	1 0 1	2 1 3	4 2 6	4 10 14	7 3 10
14	Photographs gave me ideas, so I could easily participate in class discussion.	Int1 Int2 Total	0 0 0	1 0 1	3 1 4	3 14 17	11 1 12
15	Listening to other student opinions helped me learn astronomy.	Int1 Int2 Total	0 0 0	2 0 2	1 3 4	6 6 12	9 7 16
16	It was interesting to hear other student ideas.	Int1 Int2 Total	0 0 0	2 0 2	1 2 3	7 6 13	8 8 16
17[b]	I don't see the value of discussion with peers, it just made me confuse.	Int1 Int2 Total	9 9 18	3 4 7	4 2 6	2 1 3	0 0 0
18	The lessons with the photographs made me think more about things that happen around me.	Int1 Int2 Total	0 1 1	1 2 3	3 1 4	8 10 18	6 2 8
19	In general, my observation skill has been improved since completing this unit with the photographs.	Int1 Int2 Total	0 0 0	1 0 1	7 3 10	2 8 10	8 5 13
20	I found observing scientific events more often and in more detail since completing this unit with the photographs than before.	Int1 Int2 Total	0 0 0	0 1 1	7 3 10	6 11 17	5 1 6

[a, b] The questions 8 and 17 were asked in a negative way.

Some of the questions were grouped into five categories: interests of using CRS, interests about photographs, learning with photographs, discussion with peers, and the effect of photographs on observation skill. Table 17 presents Cronbach alpha value and the mean number of students for each category. Two categories, *interest CRS* and *learning with photos*, have low Cronbach's alpha value, meaning low reliability. The remaining three categories, *interest photos*, *discussion with peers*, *and the effect of photographs on observation skill*, have Cronbach's alpha value higher than 0.75, representing reliability between the internal items.

Table 17. Cronbach's alpha and the mean number of students for each category (Intervention class 1: n=18, Intervention class 2: n=16, total: n=34)

Category	Q.	Cron-bach's alpha	Mean number of students					
			class	Strongly No	No	I don't know	Yes	Strongly Yes
Interest CRS	Q1,2	0.649	Int1	0	0	0.5	4	13.5
			Int2	0	0	0	4	12
			Total	0 (0%)	0 (0%)	0.5 (1.5%)	8 (23.5%)	25.5 (75%)
Interest Photos	Q4,5,6	0.775	Int1	0.33	1	2.33	7	7.33
			Int2	0	0.67	2.67	8.67	4
			Total	0.33 (1%)	1.67 (4.9%)	5 (14.7%)	15.7 (46.2%)	11.3 (33.2%)
Learning with Photos	Q7,9, 11	0.695	Int1	0	1	4.67	6	6.33
			Int2	0	0	2	10.7	3.33
			Total	0 (0%)	1 (2.9%)	6.67 (19.6%)	16.7 (49.1%)	9.67 (28.4%)
Discussion with Peers	Q15, 16,17[a]	0.814	Int1	0	2	2	5.33	8.67
			Int2	0	0.33	2.33	5.33	8
			Total	0 (0%)	2.33 (6.9%)	4.33 (12.7%)	10.7 (31.5%)	16.7 (49.1%)
Obser-vation Skill	Q10, 18,19, 20	0.857	Int1	0	0.5	5.5	6	6
			Int2	0.25	1.25	2.5	9	3
			Total	0.25 (0.7%)	1.75 (5.1%)	8 (23.5%)	15 (44.1%)	9 (26.5%)

[a] Responses to the negatively asked question (Q17) were transformed to be positively asked question: therefore, transformed between strongly no ↔ strongly yes, no ↔ yes.

Student *interest in using CRS* was strongly positive: averagely 25.5 (75%) among 34 students responded "strongly yes," and averagely 8 (23.5%) students responded "yes" for the question about CRS interest. Student *interest in photos* and *attitude toward learning with photographs* were pretty positive: 15.7 (46.2%) students said "yes" and 11.3 (33.2%) students said "strongly yes" for the category of their *interest about photograph*, and 16.7 (49.1%) students strongly thought and 9.67 (28.4%) students thought that the photographs helped them learn the astronomical concepts better. The majority of the students (49.1% strongly yes, and 31.5% yes) thought that *discussion with their peers* helped them learning the astronomical concepts. They thought that learning with the photographs gave positive impacts on their *observation skills* (26.5% strongly yes, 44.1% yes). The results showed that the students who participated in this study liked learning with the photographs, valued discussion with their peers, and thought that learning with the photographs helped them improve their observation skill. Most of all, they liked using the CRSs a lot.

The other Likert-type question concerned student perception about the degree of difficulty of the lessons. The answer choices were: very difficult, difficult, I don't know, easy, and very easy. Figure 16 shows the number of students per each choice. As can be seen in the figure, most students gave positive responses. About half of the students thought the lessons either "easy (12 students)" or "very easy (4 students)." The other half students (15 students) gave neutral responses. There were only three students who thought the lessons "difficult." There was none who thought the lessons "very difficult."

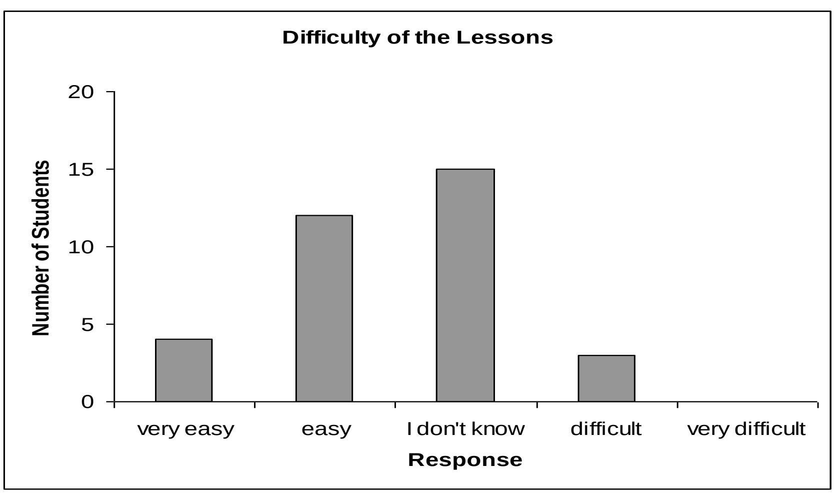


Figure 16: Student responses about the degree of difficulty of the lessons

This is very interesting that most students thought the lessons easy. In the baseline interview, the teacher had concerned that the lessons would have been very difficult for the students of this age. However, it turned out that there were only three students who thought it was difficult, and the majority thought it was easy or gave a neutral response.

Open-ended Questions Results

Student perceptions about the lessons were found in more detail from the open-ended responses of the perception (attitude) survey and the short surveys. Below, I present student attitudes and perceptions about learning using the CRSs and the photographs with the new pedagogy. In the quotes, *AttS #* represents the question number of the attitude survey, and *SrtS* represents the short survey with the date that the students responded.

CRSs, photographs, and inspiring imagination made the lessons easy, fun and interesting.

In the Likert-type questions, many students chose *easy* for the degree of difficulty of the lessons. The student perceptions about the lessons were found in their open-ended responses that it was easy to learn: "I felt that it was a great and easy way to learn. It really helped me a lot (S6, AttS #4)" and "Good and easier way to learn (S34, AttS #4)." The students felt comfortable because they felt that they knew what the teacher was trying to teach: "I liked it because we did something I knew and I felt comfortable (S30, SrtS 2008.10.7)" and "I have felt like I knew everything you were talking about in class using photographs (S23, AttS #4)." Some students thought that learning with the photographs made them feel easier, for example, "I think this lesson was pretty easy, because there were pictures to go along with it. I liked this lesson, because I could understand it. (S32, SrtS 2008.10.7)"

The students thought that the new way of learning was fun and interesting. They considered *CRSs (clickers), photographs,* and *imagination* as the three main factors that made the lessons interesting. First, the students liked using the CRSs: "I LOVE USING CLICKERS! (S11, AttS #9)", "I liked this lesson. I LOVED USING THE CLICKERS!! (S7, SrtS 2008.10.9)" and "I liked that we used CLICKERS!! (S-, SrtS 2008.10.7)" The students thought that the use of CRSs made the lessons fun and interesting, for example, "Well, I LOVE using the clickers so this to me was really, really fun. Go Clickers!! I want to use these things every day!! (S11, SrtS, 2008.10.9)", "The first reason l liked this lesson is because we get to use the clickers. (S1, SrtS, 2008.10.9)", "I enjoyed this lesson because using the clickers is very interactive and fun. (S1, SrtS 2008.10.28)", "I felt that today's lesson was fun and exciting. I liked the lesson most when we used the clickers. (S27, SrtS 2008.10.7)" and "I love using the clickers so I felt like it was really fun. I wish every teacher would do teaching with the clickers (S11, AttS #4)." The students did not only think that the CRSs were enjoyable but also thought that CRSs helped their learning, for example, "When I use the clickers it is not only fun it helps me learn better (S23, AttS #4)", "Today's lesson was very fun. I enjoy using the clickers to respond for these challenging questions (S1, SrtS 2008.10.14)", and "The clickers really helped me learn a lot, and I hope we keep using them! (S32, AttS #9)."

The students liked about learning with the photographs, for example, "I liked the lesson because we got to see pictures and could use our clickers (S-, SrtS 2008.10.7)", "I liked to use the clickers, they are fun. I also liked the pictures, they are cool. (S17, SrtS 2008.10.20)" and "I did like the lesson because it's different from our normal learning and because we get to see pictures that look cool (S9, SrtS 2008.10.20)." They thought that the photographs made them interest in learning astronomy: "I feel that the photographs and clickers made me even more interested in astronomy (S27, AttS #4)" and "In general, I guess it was pretty fun using photos and clickers. (S8, AttS #4)." The students thought that learning with the photographs was amusing and help them their learning, for example, "I thought today's lesson was fun. I liked how we could compare pictures (S26, SrtS 2008.10.7)", "I think using the pictures and clickers was fun (S27, SrtS 2008.10.28)" and "I liked this lesson because looking at the pictures and using the clickers helps me learn about astronomy and space (S14, SrtS 2008.10.20)."

Lastly, the students liked using their imagination when looking at the photographs. For example, S15 wrote in the short survey that "Today's lesson I thought it was fun and cool how we could imagine (SrtS, 2008.10.9)" and "I liked everything about this lesson and thought it was fun because we could imagine! (SrtS 2008.10.14)" When learning with the photographs of the moon, some students even felt that they were actually being on the moon: "I thought it was a cool lesson. I actually felt I was on the moon walking (S17, SrtS 2008.10.9)" and "Seeing the photographs made me imagine like am actually being on the moon (S2, AttS #4)." Such imagination inspired them to bring their prior knowledge into the class, for example, "It was sooooo much fun to pretend that we were on the moon. I thought that it was great to have us use our imagination and what we know (S8, SrtS 2008.10.9)."

Learning with CRSs and the photographs encouraged the students to participate in classroom discussion. Students felt more involved in class and felt comfortable to participate in classroom discussion when the CRSs and the photographs were used. For example, they wrote, “I have felt more involved when using the clickers and the photographs helped me learn a lot more in class (S15, AttS #4)”, “I liked the use of the clickers because they helped me pay attention in class. (S12, AttS #4)” and “I liked the pictures because it was easier for me to participate in class. Using pictures surprised me because we don't usually use them (S-, SrtS 2008.10.7).”

One of the reasons that CRSs made the students feel comfortable was because of its *anonymous feature*, which helped them increase their confidence in class. Some students noted that they liked the anonymous feature of the CRS, and it helped them express their opinion in classroom discussion: “I liked today's lesson because I got some of the answers correct. Also the clickers help make my answer anonymous which I like (S24, SrtS 2008.10.28)”, “The clickers are awesome, now I don't get scared to speak up (S3, AttS #4)” and “I liked using clickers so nobody would make fun of you that you choose that answer (S17, AttS #4).”

Discussion helped learning because different perspectives could be shared. The students recognized the value of the classroom discussion. First of all, they were surprised by the ideas that other peers brought up to the class, for example, “What surprised me was what people thoughts were (S-, SrtS 2008.10.7)” and “What surprised me is what people came up with (S5, SrtS 2008.10.9).”

They thought that listening to other's opinions made them learn various ideas about a concept and it made them reflect upon their previous answer: "I got to learn more ideas than just mine so I could think about my answer more (S12, AttS #7)" and "Our discussion with my classmates help because we have double the thoughts and help me learn more and get more ideas like if we did have homework (S5 AttS #7)."

As the result of reflection after hearing other's thinking, the students found which thinking was wrong and were able to correct their thoughts by themselves, for example, "The discussion with my classmates helped me to learn astronomy because it told me what other peoples' ideas were. This made it easier for me to see if my idea was correct (S1, AttS #7)", "I got to hear other people's opinions, and hearing other people's ideas and why they think those things, so that helped me understand things better (S32, AttS #7)" and "It helps me see what I did wrong or if the same person was thinking what I was thinking (S17, AttS #7)." Sometimes they corrected each other's ideas, for example, "The discussion with my classmates was most important because if I was thinking wrongly or the wrong way my classmates would correct me (S2, AttS #7)."

In general, the students perceived that they could learn better by listening to different perspectives while participating in classroom discussion: "I think the discussion with my classmates helped me learn astronomy by hearing other people's ideas and looking at something with a different point of view (S31, AttS #7)", "The clickers really helped me learn more about science (astronomy), because seeing what other people thought helped me understand things better (S32, AttS #4)", "It helped me understand because if I don't know something and someone else does and says it, that means I learn a lot better (S6, AttS #7)" and "It helped me learn astronomy because I got to listen what the other kids had to say (S36, AttS #7)."

Most students valued the discussion and liked it, saying "This lesson was fun because I like hearing other peoples ideas or thoughts (S13, SrtS 2008.10.9)," however, there were few students who thought that discussion made them confused, "I don't think that the discussion with classmates helped me learn, it just made me more confused (S8, AttS #7)", or listening to others' thinking was boring, "I thought it was boring, just sitting there and talking about the answers (S17, SrtS 2008.10.20)." Some did not like to debate, "It did not help me because if someone said something different than that person would argue with you until you said they were right (S13, AttS #7)," or did not like to be the only person who had a different answer, "What I disliked is everybody voting against my answers. I don't like being the only person to have a different answer (S35, SrtS 2008.10.20)."

The photographs helped the students connect a scientific concept to their prior knowledge, visualize an image, and showed unexpected events. The photographs that were used in the lessons played several pedagogical roles. As mentioned earlier, the photographs made the lessons *fun and interesting*. In addition to its amusing role, the photographs helped the students *connect the new scientific concept to their prior knowledge* that they had earned from daily experiences. For example, "By seeing pictures on the screen, it helped me make connections in my head (S31, AttS #4)" and "I loved today's lesson. The photographs are amazing and the world looks more fascinating than ever. The picture of day+night in one image is pretty cool with all of the lights you can see. Using what we already know and learning more is great! (S-, SrtS 2008.10.20)"

Visualizing an image by looking at the photographs helped the students learn the scientific concepts better, for example, "They [photographs] helped me because I knew what it looked like so I have a good picture in my mind and I understand it better (S3, AttS #5)", "It helped me by making a picture in my head that I could use along with my answer to make it more detailed (S6, AttS #5)", "It helped me visualize how things work (S28, AttS #5)" and "I think the photographs helped me learn because when I saw the different views of the earth, the sun, and the moon, I could see the cause of the seasons (S31, AttS #5)."

The photographs were effective in demonstrating the *evidence of unexpected events* that the students had never expected to happen. For example, "The photographs helped me by how it shows me what everything looks like that I never expected (S16, AttS #5)" and "I think the photographs helped me learn the concepts of day-night and cause of seasons by showing me more things I never knew before and never saw before (S4, AttS #5)."

The gratuitous detail of the photographs represented real scientific phenomena, which helped the students learn the concepts. For example, "The photographs helped me to learn this because they showed me exactly what was happening ... (S1, AttS #5)", "It showed me how it happens in real life and it made me think more open minded (S9, AttS #5)", "The photographs helped a lot because we could see actual photographs of what certain things looked like (S32, AttS #5)", "I think they helped me because I was able to see how all this stuff worked (S22, AttS #5)" and "It helped me more by seeing the photos. I did not understand white night until I saw the photo (S29, AttS #8)."

In addition to the above roles, the photographs showed the students different point of views, "I think the photographs helped me learn because when I saw the different views of the earth, sun, and the moon, I could see the cause of the seasons (S31, AttS #5)", and encouraged them to participate in class, "I liked the pictures because it was easier for me to participate in class. Using pictures surprised me because we don't usually use them (S-, SrtS 2008.10.7)."

Summary

In general, student attitudes toward the lessons were very positive. They thought the lessons were easy, fun and interesting. They liked using CRSs because they had a lot more fun than without it. Some of the students reported that they liked its anonymous feature. The students also thought that they felt more engaged when learning with CRSs and the photographs. In addition, they recognized the value of sharing their opinions in classroom discussion.

Several pedagogical roles of the photographs were found from the student responses. The students thought that the photographs made the lessons much fun and interesting; played a role connecting the new concept to their prior experiences; encouraged them to visualize an image in their minds; demonstrated evidence of unexpected events; represented scientific phenomena objectively with its gratuitous detail; showed various point of views; and made them feel comfortable to participate in class.

Teacher Attitudes toward the Lessons

In this section, I present findings from the teacher interviews. As this type of lesson was new to the teacher, she encountered several difficulties while conducting the lessons. Here, I introduce some factors that she reported as barriers of performing the new pedagogy. And then, I present her perceptions about the new curriculum unit with the use of CRSs and the photographs.

Difficulties of Conducting the New Pedagogy

Teacher-Learning of Technology-Enhanced Formative Assessment (TLT) project was to investigate teachers' changes in their practices and philosophies about teaching and learning when they had the intervention of the TEFA pedagogy. As the part of the TLT project, factors that affected science and mathematics teachers' implementation of TEFA pedagogy were investigated (Lee, Feldman & Beatty, 2009, 2011). According to the study, there are mainly ten common factors that inhibit the teachers from implementing the TEFA pedagogy integrating CRSs: *hardware and software* problems; *time and curriculum pressure; student behavior, attitudes and ability; operating technology* reliably and flexibly; *developing CRS questions* to achieve desired purposes; *integrating TEFA into curriculum; facilitating classroom discussion* in a student-centered way; *practicing formative assessment* by eliciting student thinking and adjusting teaching; their *ways of being a teacher;* and circumstantial factors that affect their teaching in general, beyond just TEFA (Lee, Feldman, & Beatty, 2011).

Among those ten common factors, Mary mainly struggled with three factors in this study: difficulty of *facilitating classroom discussion*; *time and curriculum pressure;* and *student attitudes and abilities*. First of all, Mary struggled with how to facilitate the classroom discussion. This new curriculum unit required her to play a new role as a *facilitator* of classroom discussion. Although she was a very experienced teacher, implementing this new role in classroom discussion was a challenge for her. She said, “Group management, I think, was a big challenge (2008.10.24).” She was especially unsure about how long the discussion should go on or when to move to a next topic: “The biggest challenge was how to keep it moving. I wasn't sure how long to allow the discussion to continue. I think that was the biggest challenge (2008.10.10)”, “The only thing I'm worried about is that if I'm moving too slow they're going to get bored with this after a point, but then I worry about moving too fast and having a lot of kids miss some of the point because I really don't like having to repeat everything. I think that's going to turn them off but it's too hard to hear everyone (2008.10.10)”, and “…and still leading the discussion is hard for me with certain questions. I'm not always sure when I should stop the discussion and move on. That's still difficult for me (2008.10.30).” In fact, she spent considerable time to hear from almost every student, which often dragged a class. She was also concerned about the level of student understanding in regard to manage the classroom discussion, “…there were a few days when I didn't feel I knew how to move it forward. I was, maybe I was too worried about everybody being at the same level of understanding as everyone, you know, each student being at the same level of understanding and so I was pretty unsure myself at certain points (2008.11.10).”

Due to the nature of lengthy discussion and the teacher’s slow pace of conducting the discussion, it took much more time to cover the curriculum unit than we had expected. In the interview, Mary reported the slow pace of the lessons, for example, “…they aren’t going as quickly as I hoped, and they’re taking more time right now (2008.10.10).” She reported the lack of time and felt pressed for the time: “I'm feeling like I'm pressed for time (2008.10.15)” and “And the time, the time constraints. I felt as if I was taking way too much time on the topic (2008.11.10).” She thought that the topics would have been covered better if there were enough time to do so: “I just keep thinking of the fact that there's so much that could be done better if we had the amount of time needed to do it, as far as the objectives that we're teaching (2008.10.30).”

As a last remark, Mary reported that the students at this age might have not been prepared to participate in a lengthy whole classroom discussion and suggested to mix it with some small group activity/discussion: “I think we do need to mix some small group work with the whole class discussion. I think it's too hard for kids this age to do, just full class discussion all the time. For some kids it's great but the whole class it can't always sustain (2008.10.15).” Mary thought that the younger students such this age needed to have small group discussion in advance of having large group discussion: “I think just keep doing some small group then larger group, going from small group to large group. I think it’s because kids at this age, it’s hard for them to sit for long periods of time in one spot and just discuss and look at photos. A lot of it’s their age. For some it’s just not active enough for them (2008.10.24)” and “I think the use of photos and the clickers plus being able to discuss in groups and then with whole class, I think that went well. Um, just using photos and whole class discussion is too, too abstract for these kids. They need someone to talk first in small groups to help develop their ideas before sharing it as whole group (2008.11.10).” Although most students actively participated in both small group and whole class discussion, a few students participated less when the discussion moved into whole class from small group, for example, Mary said, “But I know that there are a couple in each class to that aren't getting it. And I think those are the kids that get lost in the whole class discussion. They just kind of tune out when that's happening (2008.10.30)."

<u>Teacher Perceptions about the Lessons</u>

Although Mary reported such difficulties in conducting the new pedagogy, her perceptions about the new pedagogy and the new curriculum unit were positive in general, as described below.

<u>The new pedagogy made possible for the teacher to hear various student voices.</u>

Although Mary had been challenged to the slow pace of covering the curriculum in the new pedagogy, she was pleased to hear various student voices, especially from the ones who normally had not participated in a traditional class: "I think the fact that it gets more kids than normal to express their thoughts is a great thing. Even though it seems like sometimes it drags a little bit I still hear more students actually participate, at least put their thoughts into words that sometimes won't speak for days otherwise. I think that's a very positive effect (2008.10.15)", "… The length of daytime hours, that's been another one because I have to stop and think about it myself, and they're really getting into the discussion about it. Kids that normally will not even say two words in class are all involved in it (2008.10.30)", and "I was pleased about the amount of students that participated, that actually participated in discussions. I wasn't sure how that would go. But some students really surprised me, and [we're?] part of every single class, and these students that I didn't, I didn't see participating before, as much, before the study (2008.11.10)." Mary thought that the new pedagogy gave motivation to participate in class to the students who normally did not participate in.

<u>The new pedagogy helped the students develop their reasoning deeply.</u> While the students participated in classroom discussion, they could develop deep reasoning, and Mary was impressed by the level of discussion that the 6th graders could pull out, which she had not expected before. For example, she noted, "I was really pleased and surprised at the level of dialog and discussion that we observed this week (2008.10.24)" and "…just that how impressed I was by ability of kids to actually get and discuss this topic in a meaningful way. And, much higher level than I ever have expected with these 6th graders would, would be able to do (2008.11.10)."

Especially, she realized the importance of giving the students a chance to get confused about a concept, which usually promoted to bring active discussion, for example, "It's really getting them to all think and I can tell there is confusion, but that's where the learning happens, because if it looks like they're confused, they're actually thinking about it, and it's different than someone who's not paying any attention. (2008.10.30)"

<u>The new pedagogy helped the teacher find the gap between what she was teaching and how the students understood it.</u> By listening to student voices, Mary was able to understand the gap between what she was teaching and how the students understood it. For example, she said, "I felt very positive about it. There have been times when I realized how confused they really were but it was a good thing cause I wouldn't get that understanding about their thinking just doing it that traditional way. I wouldn't understand exactly where the breakdown of understanding was, here it's easier to see. And it's great to hear some students whose explanation came out of a science book and it came from their own discussions and thoughts, and it's pretty amazing to me

(2008.10.30)", and "The most positive thing was hearing some of the students' explanations that were so deep with understanding and then, others, they didn't get it quite completely, but you can tell they were on their way to understanding. They were forming understanding. And, you, usually you can not see that. You know, it's happening right, as we are learning as they are learning it. You could, I think that was the most highlight because in most traditional classes you don't spend that much time to discussing, so you don't really have the sense of what, where each child is (2008.11.10)."

<u>The students learned metacognitive skills of what to do in discussion.</u> Mary did not only think that the new pedagogy helped the students with their content knowledge, but she also thought that it helped them develop their process skill. Mary observed that her students learned how to listen to other's opinions, and how to debate others if it differed from their own thinking or how to modify their previous ideas when they found flaws in it, as they participated in the class with the new lessons. For example, she said, "They didn't all agree but they all talked well within their groups (2008.10.15)" and "You know also that they really listened to others' opinions and were able to take what they were able to use those ideas to change or modify their own, that was just an amazing process to see them go through (2008.11.10)."

In addition, she observed that some students became the leaders of the discussion and they could run the discussion on their own without her, "I think both groups [the two intervention classes] throughout the week had some very deep discussions, especially within each class, I saw some kids become the leaders of their group, and it's nice to see that they can run little discussions on their own, because they do become much more engaged and involved in their learning when they're doing that, than if I'm just standing up there asking them questions (2008.10.30)" and "I feel, especially in one of the classes, the intervention class 2, seems like they were really able to almost, at a certain point, sometimes run the discussion by themselves when it gets going, although even the intervention class 1, a couple of times, so I feel like they, there were a few kids that really benefit from this type of learning and ah, develop, almost become like the leaders of the whole group, as a whole (2008.11.10)."

The photographs motivated the students to feel comfortable to participate in discussion.

Mary's attitudes toward using photographs were quite positive. She reported that the photographs helped the students speak up their thinking and encouraged them to participate in classroom discussion: "They [the photographs] definitely get kids talking more, and also get more of the kids involved. And those two points are key to learning. It helps me understand what they're thinking better as I'm teaching (2008.10.10)" and "Just that I really feel that I've gotten to know the kids a lot better in each class, and I keep thinking that it would be nice to use these [the photographs] with the classes that are not part of the intervention group, and how much they would benefit from it. I just feel that they would because it [the photographs] gets them talking more, and more engaged and involved in their learning (2008.10.10)."

Mary thought that the photographs were *a great starting point of discussion*, "I felt for the most part it[photographs]'s been very helpful, because it's a good starting point. Everyone has something to say, even if has nothing to do with what we're supposed to be talking about. I think everyone is comfortable starting at that level. No one feels like they don’t have something to add to class for the most part (2008.10.30)” and “I think it [the photographs] really, they really encourage more kids to participate. Most kids felt that, especially in the beginning that they could comfortably discuss them. Because it wasn’t always about being right or wrong, a lot of time it was just asking them to discuss their observation or what they noticed. (2008.11.10)”; and *a great motivating point during the discussion*, “It [photographs] is one of the motivating points to get them engaged, and sets the stage for what’s coming next. It kind of introduces, so I think it’s necessary. (2008.10.30)”, “They [the photographs] were great motivator. They really got kids thinking. (2008.11.10)” and “I think they [the photographs] were very positive, especially the penguin, they love animals, and I think it really surprised them to find out what time of day or night it was in certain photos. They were very motivating (2008.10.24).”

<u>The photographs helped the students connect what they did in a group activity to what really happened on earth.</u> Mary thought that the photographs also played a role as *a great reference point* when the students explained their thinking, especially when the students worked in small group activities. She thought that the photographs helped the students connect what they did with light bulbs and globes in the group activities with what it really happens on earth, saying, “I can see that having the photographs helped them a great deal. Using the globe but then having the photographs to refer to helped them to figure out the direction that the earth rotates without someone having to tell them. And also being able to see the different times of day and different parts of the world from the photos. That’s just one thing that would add to them just using a globe and a light bulb *because they’re actual photos*. It's not just a simulation. I think they can connect the

activity they might be doing by seeing the real thing. Instead of just modeling it, but they can't turn the earth at the same speed or have it be in the direction of an actual image of the sun shining on the earth. I think they can take the model and refer back to the actual image. I think that's a nice addition (2008.10.15)." In addition, Mary thought that the photographs were helpful when the students were trying to explain their thinking, "And, they provided reference points for them, too, when they were explaining something (2008.11.10)."

Summary

Mary, who was a very experienced teacher having taught middle school astronomy over 10 years, encountered difficulties of how to manage the classroom discussion when she implemented the new pedagogy with the new curriculum unit. She was unsure when to stop the discussion and to move on to the next and how to balance the speed of discussion in order to cover the topics within the limited time. She also thought that the 6^{th} graders at this age had limited time span and could not participate in a lengthy whole classroom discussion.

In spite of such difficulties, Mary saw several positive impacts of the new pedagogy. First, Mary thought that the new pedagogy made possible for her to hear various student voices, especially from the ones who normally had not participated in her traditional class. Second, Mary was amazed by the level of the discussion that her students brought up. She had not expected such deep discussion and the sound reasoning that her students could develop in the new pedagogy. Third, Mary observed that her students were learning how to listen, how to debate others, and how to modify their own ideas in discussion, and was pleased by observing the students who could run the discussion without her. Fourth, Mary thought that the photographs played a great role as a motivator of classroom discussion. The photographs made her students feel much comfortable to participate in classroom discussion, and encouraged them to speak out their opinions. Finally, Mary thought that the photographs helped the students connect what they learned in class with the real phenomena. The photographs played a role of a reference that the students could link what they worked with light bulbs and globes with what really happens on earth.

CHAPTER 5

DISCUSSION

In this chapter, I discuss a student-teacher interaction model and three important teacher questionings in the model; stages of misconceptions; and the pedagogical roles of the photographs and CRSs in the lessons.

First, in the previous chapter, I explained the various teacher discourses and student discourses and described three types of student-teacher interaction patterns. These patterns can be combined to one unified model. The most important teacher-questionings in the lessons of using the photographs and CRSs in the discussion-oriented pedagogy are *"what do you see in the photo?*, asking the students to observe information that the photograph contains; *"what do you think it happens?"*, asking a conceptual question to the students to recognize a phenomenon from the photograph; and *"why do you think it happens?"*, requesting the students to reason for their thoughts.

Second, as one of my research interests, I investigated several misconceptions that the students had about the concepts of day-night and cause of seasons. Those misconceptions have different strengths. Some misconceptions were very naïve, and were easily changed with little instruction. These misconceptions can be called *primitive conceptions*. They usually come from the students' prior experiences before having any instruction about the concepts. Another group of misconceptions come from *incomplete understanding* of a new scientific concept in which students may choose a correct answer by memorization but they do not exactly know why it happens. Therefore, their conceptions are partial, very fragile, and can be changed easily by intervention. The last group of misconceptions is *logical misconceptions*. The word, logic, does not mean that it is truly correctly logic, but rather it means that the students build a conception in their own way, which they believed to be logical. The seed of the logical misconceptions may come from a *phenomenological primitive* (diSessa, 1993) or from any other previous conceptions.

Third, I discuss the pedagogical roles of the photographs in the lessons. The photographs in this study played much more active roles than when they were traditionally used. The photographs used in this study were fun and interesting; played as a starting point, a motivator, and a reference of classroom discussion; encouraged student imaginations; showed the evidence of unexpected events with the gratuitous details; helped the students connect the new concept with their daily experiences; and helped the students bring their own questions that were great discussion topics.

CRSs also played several pedagogical roles in this study. They were fun and interesting, helped the students feel comfortable to speak out their opinions due to the CRSs' anonymous feature, and that helped the students learn from various perspectives by listening to others' thoughts. In the below, I explain these with much details. In the later part of this chapter, I describe the implications of the study with future work and conclusion.

Student-Teacher Interaction Model and Three Important Teacher-Questionings

The students and the teacher who were engaged in the new pedagogy shared various discourses as described in the previous chapter. Based on the discourses, three different types of student-teacher interaction patterns were observed, depending on 1) when only photographs were provided and conceptual questions were not used, 2) when both photographs and conceptual questions were used and correct answers were not provided until the end of the discussion, and 3) when both photographs and conceptual questions were used and correct answers were provided in the middle of the discussion.

These three types of interaction patterns can be simplified into one unified model (Figure 17). The circles of the above row in the figure show the teacher discourses, and the circles of the below row show the student discourses. The teacher starts the lesson with showing the students *photographs*, noted as the grey box, and asks *requesting preliminary observation (Obs)* questions, such as "what do you see in the photo?" In response to the teacher *Obs* discourse, the students describe the information that they perceived from the photographs as static (*direct description, DD*) or as dynamic (*dynamic direct description, DyDD*). Then, the teacher asks a *provocative concept development question (CDQ),* which were mostly asked with CRS technology *(CRSQ)* in this study. After the conceptual question is asked with the CRS technology, the students respond their answers by voting with the CRS devices (clickers). When the system collects the student responses, it shows the result with a histogram. The teacher *reads off the histogram result (H),* such as "ok, so majority chose c." Based on the histogram result, the teacher starts the whole classroom discussion, asking *reasoning questions (RQ),* such as "why do you think so?" or "why did you choose the answer?" The student responses for that often bring their early stage of *visual reasoning (VR)* or *dynamic visual reasoning (DyVR),* such as "I chose c because I see …" or "I think it is … because it looks like going down… in the photo."

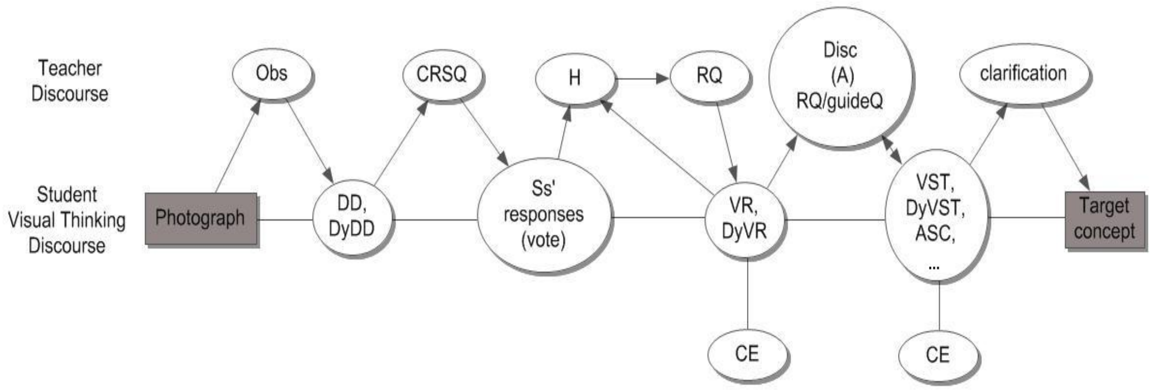


Figure 17: Student-Teacher Interaction Model

The teacher often goes back to the histogram *(H)* and asks the reasoning *(RQ)* for those students who have different answers. She also repeatedly *encourages students to participate into discussion (Disc),* asking such as “anybody else to add?” or “do you have any other thought?” This helps the students bring their various ideas. While the teacher encourages the students’ participation and as they hear various thoughts from their peers, they develop higher-order thinking such as *visual spatial thinking (VST), dynamic visual spatial thinking (DyVST),* or *applying a scientific concept (ASC).* Sometimes, the teacher needs to reveal what the correct answer is *(A)* during the discussion to start up the next stage of discussion, especially when the conceptual question *(CDQ)* is a discrepant question. And, she often uses reasoning questions *(RQ)* or guidance questions *(guideQ)* to help students develop reasoning. During the discussion, students often bring their daily experiences *(CE).* At the end of the discussion, the teacher summarizes student responses and clarifies the concept *(Tclarif).* In the process, the student conceptions become closer to the target scientific concept, the grey box in the right side of the figure.

In such an interaction model, three teacher questionings play important roles (Figure 18). First, the question "*what do you see in the photograph?*" asks students to observe the photographs and to recognize the environments and the details of the photo. At this stage, the students gather the information that they can observe from the photo. Second, the question, "*what is happening?"* presents conceptual questions that ask the students to answer for. Last, the question, "*why do you think so?"* asks the students to develop their reasoning and to share their ideas with their peers. Therefore, those three teacher-questionings are the basis of the pedagogy that uses photographs for the purpose of classroom discussion.

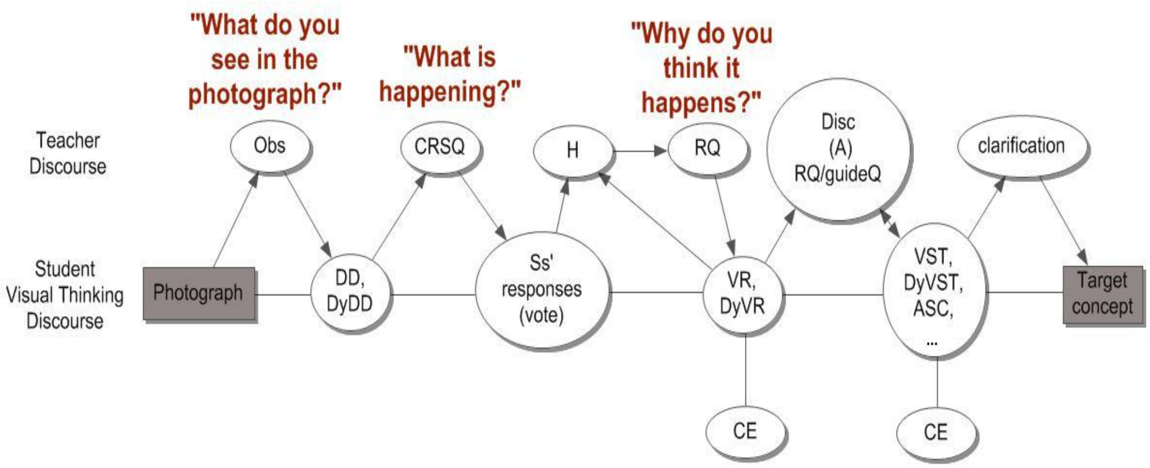


Figure 18: Three important Teacher-Questionings

These three teacher-questionings are somewhat similar to what Abigail Housen (2001) suggested in her *Visual Thinking Strategies* (VTS) curriculum to improve student critical thinking and language skills through discussions of visual images in art education. The VTS curriculum has three foundation questions: "what is going on here?; "what do you see that makes you say that?"; and "what more can you find?" The first question invites students to examine the image carefully. The second question asks students to cite evidence for their interpretation. And the third question encourages students to keep on searching. Therefore, Housen's VTS curriculum is focused on developing student language skills by describing what they can see from an image, creating a story from the image, and finding evidences to support their story. On the other hand, TJ+TEFA instruction is focused on developing student scientific thinking by observing a photograph, finding a phenomenon (or information) that the photograph represents, and reasoning for why it happens from the information that they gather from the photograph. In TJ+TEFA instruction, students do not only perceive an image but also they transform, move or rotate the image in their mind's eyes.

Misconceptions

This study investigated various misconceptions that the students had about the concepts of day-night and seasonal changes on earth. Some misconceptions were easily overcome with little instruction, but some others were deeply rooted and very strong to be changed. Hereby, I categorized three groups of misconceptions in the below.

The first group is *primitive conceptions*. They are very naïve conceptions and often preconceptions that the students brought to class before having an instruction about the concepts. This first stage of misconceptions is often presented by simple descriptions about a phenomenon that has been experienced in daily lives. These naïve conceptions often bring little logical reasoning. For example, such naïve conceptions are "*Day and night happen on earth due to people's needs (Day and night happen earth because if we didn't have day then we would be sleeping all the time and if we didn't have night the same day would go on and on forever: Int1, 5, pre)"; "Day is light out and night is dark* *out"; "Seasonal change on earth is due to weather"; or "The earth has four different areas having each different season."* These are not strong and can be easily changed to other conceptions when the students receive new scientific information. Few students, however, hold the same primitive conception even after they learned the concept.

The second group is *incomplete understandings*. This stage of misconceptions is from partial understanding of a new concept. Students in this stage use some logical but partial and fragile reasoning when receiving a new concept. Some students may simply memorize the concept, but do not fully logically understand it. For example, some students responded correctly that the seasonal change on earth is caused by the earth's axis but could not give any further explanation about the *tilted* axis. Instead, they showed the misconceptions such as that "s*ummer is when the earth faces the sun and winter is when the earth faces the moon"* or *"summer is when the earth faces the sun and winter is when the earth faces away from the sun."*

The last group is *logical misconceptions*. This is the strongest stage of misconceptions. They are not easily changed even after having extensive instruction, rather they become foundations of building a new misconception when combined with new information. Students have logical reasoning in their own way and build a firm confidence in their beliefs. For example, well-known strong misconception is that "*seasonal change on earth is caused by the different distance between the sun and the earth. In summer it is closer, and in winter it is further."* One of interesting misconceptions found in this study was that "*seasonal change on earth is caused by the earth's tilted axis. When the axis is tilted toward the sun it is closer, and when the axis is* *tilted away it is further from the sun."* So, in this misconception, the students learned that the seasonal change on earth is caused by the earth's tilted axis but also thought that it should be related to the distance between the sun and the earth. As a result, some students developed a new misconception that the earth's tilted axis affects the different distance large enough to create seasonal changes. Another example of this category is that *"distance between the sun and the earth causes seasons on earth. When it is closer the earth gets scattered sunlight which causes winter on earth, and when it is further the earth gets more direct sunlight which causes summer on earth."* This student had the conception of direct sunlight causing to increase the temperature on the earth surface and learned that the distance to the sun is closer in winter and further in summer in the Northern Hemisphere. But he also had the strong conception about the distance related to temperature. As a result, he developed such a sophisticated misconception. Therefore, students in this category of misconceptions may develop *hybrid models* (Vosniadou, 1994), which is the combination of a new scientific concept with their prior knowledge, resulting new misconceptions. These are often very firm, sophisticated and hard to be corrected because they have been built on their logical reasoning.

Pedagogical Roles of the Photographs

The photographs used in this study played several pedagogical roles (Figure 19). These roles were found from the student responses on the attitude survey and the teacher interviews. The photographs made the lessons fun and interesting, showed the evidence of unexpected events with its gratuitous details, encouraged the students' imaginations and helped them connect their prior experiences to a scientific concept. Most of all, the photographs could initiate discussion, motivate discussion, and become a reference point of discussion.

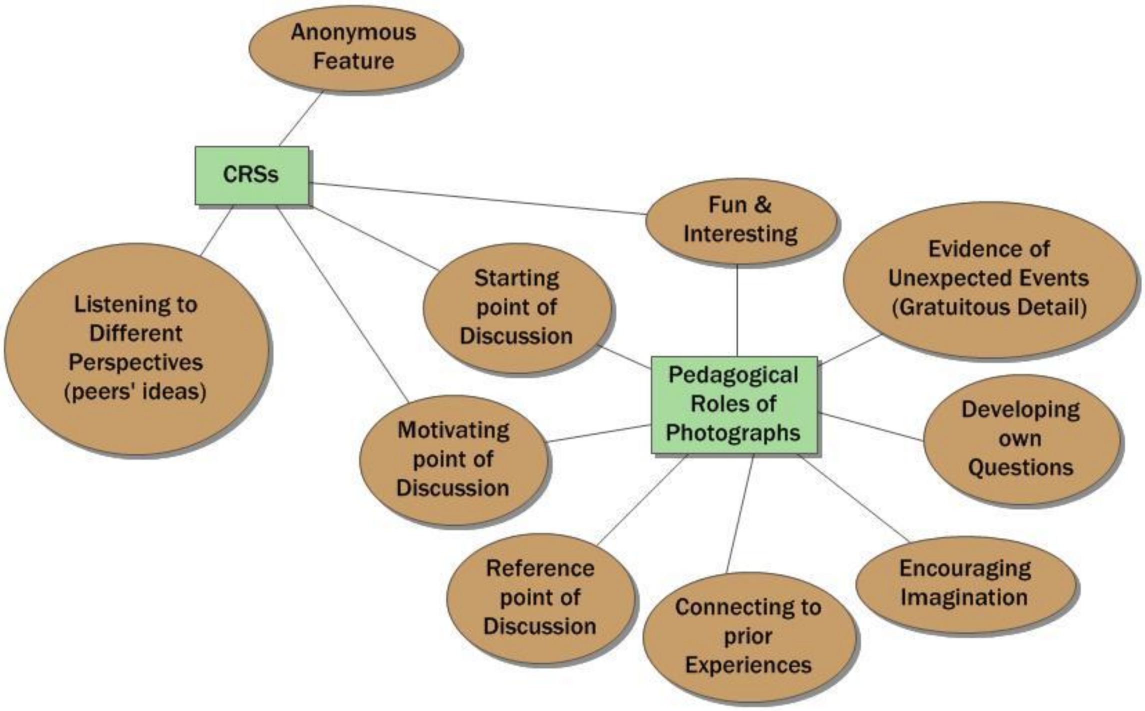


Figure 19: Pedagogical roles of the photographs and CRSs

In addition to these roles, one other pedagogical role was observed. In the intervention class 1 on day 4, the teacher showed the photograph of the earth taken from the moon (Figure 20) and asked her students if they had any question about the photo.

Figure 20: The photograph of the earth seen from the moon

And below is the list of the questions that the students brought from observing the photograph.

- *Why can't you see the stars in the sky? (S6)*
- *Why can't you see any green in the land? Why can't you see any green grass? (S13)*
- *If you fell where would you go?... if you fell and you jumped off the moon? (S3)*
- *Um, can you see any other planets from the moon? (S1)*
- *Why is there only one little piece of it? (S5)*
- *I want to know if there's a storm happening because you can see some clouds rotating. (S14)*
- *Um, I was wondering how come only the bottom, how come it's the bottom half, like instead of how come it's not like day or night side by side -. (S15) [Teacher clarified the question, T: Oh okay, why are we seeing the like the top half of what looks like of the earth and it's not split the other way? In the other direction? S15: yeah.]*
- *How come you can't see the sun? (S16)*
- *Um, like I was wondering if the earth is showing (unclear) half of Africa, Asia, Europe and Australia (unclear) and you (can't see) if it was stormy or very cloudy -. (S8)*
- *How long does it actually take to get to the moon? (S11) . . .*

As can be seen in the quotes, just one photograph brought up a lot of interesting questions. Some questions are related to *direct description* (S6 and S13), some are related to *visual reasoning* (S14), some are related to imagination (S3 and S11), and some others are related to *visual spatial thinking* (S15). Each question is great for classroom discussion topic. So, the last pedagogical role of the photographs is that it helps students develop their own questions, which can become great discussion topics (Figure 19).

Figure 19 also presents the pedagogical roles of the CRSs. Because of its anonymous feature, the students felt comfortable to participate in classroom discussion. As a result, they could learn from different perspectives by listening to their peers' various ideas. The students liked to use the CRSs because using CRSs was enjoyable and playful. It amused the students and motivated their interests in class.

Implications of the Study and Future Work

In the above, I listed three different groups of misconceptions, *primitive conceptions*, *incomplete understandings* and *logical misconceptions*, and presented their broad definitions. It would need more study to verify its sophisticated nature and to present more detailed definitions for each category, and to understand how each group of misconceptions are formed and how they would be changed when there is new information. It is beyond the scope of this study to verify in what ways and to what success TJ+TEFA instruction overcomes those misconceptions. Therefore, those topics remain as future study.

While the students were participating in classroom discussion, some student responses indicated their conceptual change, and how conceptual change could happen in classroom discussion can be inferred from their *reasoning status discourses*. Figure 21 shows the hypothetical model of student conceptual change in classroom discussion. The students have their initial conception *(conception i)* and represent their thinking *(claim)*. They hear other student thoughts while participating in the discussion, and bring their questions *(questioning)* into the discussion if there is something that they wonder or find any mistakes in others' reasoning statements. Some students experience confusion *(confusion)*. As this procedure repeats, some students develop *(change)* a new conception (conception i+1). This whole procedure may repeat until their conception gets close to the target concept. This hypothetical model needs more thorough study to verify it and it remains as a future work.

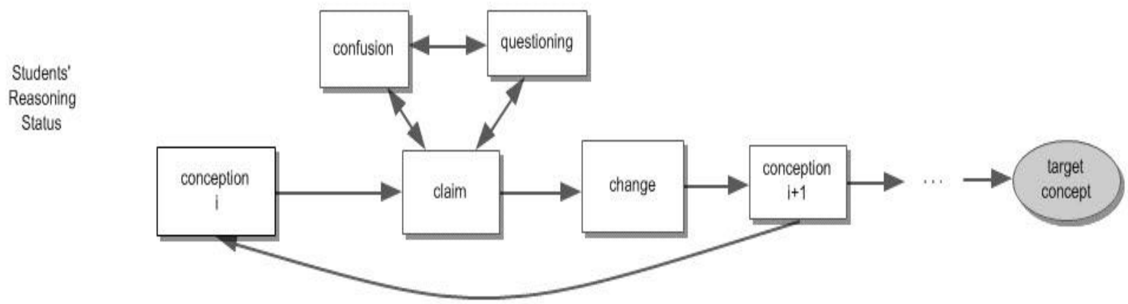


Figure 21: Conceptual change in classroom discussion

It seems to be important that the students experience some *confusion* in conceptual change. I noticed that there were two kinds of confusion that happened during classroom discussion. One is the confusion that can lead students to develop their reasoning and to have conceptual change. For example, the below is the episode in the intervention class 1 on day 14. The students in the class were discussing the question about the different length of daytime at different places.

Please choose scientifically correct statement(s).
Choose all that apply.

a) The place of A will be nighttime during 24 hours.

b) The place of B has shorter daytime than at the place of D.

c) The place of C has the longest daytime

d) The place of E will be daytime during 24 hours.

The histogram result showed that all the 18 students chose d correctly, 17 students chose a, 7 students chose b, and 5 students chose c. One student who did not choose a was because he thought the sun might be seen on horizon at the place A. It was apparent that all the students were able to recognize white night at the place E and polar darkness at the place A. So the classroom discussion was focused on the choice b and c. During the discussion, one of the students said that he chose all of them, and he explained why he chose b.

> S6: Because the choice b says place of B has shorter daytime than the place of D. Cause if you really look, D is farther away from the nighttime of the earth, and B is closer. And if it's closer to the beginning of nighttime, it would have a shorter day. [00:13:19.15]

So the student in his quote mentioned the day-night line and the discussion continued.

> S15: For B, it looks like, C is, even if it goes around it looks like it has shorter distance to nighttime. Cause B would go around and get to where A is when D is at, like, getting closer. …
>
> S15: It looks like B has a shorter distance.
>
> T: That B has a shorter distance to go. Or a shorter amount of daylight hours, you're saying?
>
> S15: Yeah.

T: Why is that, though? What's causing that to happen?

S15: the tilt?

T: Okay, you're saying the tilt of the, earth's tilt. Okay. so it doesn't have anything to do with how far it is from this line here, this day and night line? Or how far day is from the day and night line. It has to do with this tilt. Okay, S8.

S8: Can I use the globe?

T: yes, you can.

*S8: [takes the globe] [She positioned the globe like the way shown in the picture] It's like this. So, okay, so the earth is spinning. [turns the globe] and up, up here, it was facing away from the sun, like the sun was right here, then, um, up here would be winter, and then down here would be like facing towards the sun, so it would be summer, and usually in winter you have shorter daylight hours and then it's facing away from the sun, in B, which is right here, somewhere down there, it's in winter right now, so, it's winter, so it would have a shorter, shorter day, less daylight hours than D, which is like down here, near the equator, which is facing toward the sun, so it would be summer and have longer daylight hours, and *then C, which is like at the equator would have like, it would be, I don't really know how to explain it, but it would have just like, like, almost the longest, well not exactly the longest,* but B is winter and D is summer, so tilt towards the sun would affect it. [00:20:29.00]*

In the above quote, S8 gave good explanation about the reason for seasonal change and the length of daytime, but started to be confused about the length of daytime at the place C. After hearing what S8 said, S6 became confused too.

*S6: Well, now *I'm confused because of c and d. Cause I was looking at it from C being the longest.* But I didn't.*

T: You were basing your decision on how far it looked like each point was from the day and night line.

S6: I guess I didn't clearly look at C and D. So.

T: Do you understand what S15, S7, and S8 were talking about, how they based their decisions?

S6: Yeah.

T: Okay. Anyone else that choice c? Can you explain what your thinking was?

T: So how would it be like at C? Do you think it would have, C would be a longer day than B? Would it be a shorter day than D and E? What would it be like?

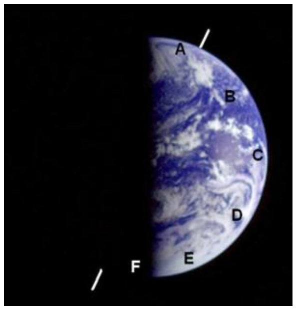
*S8: (inaudible) because like (inaudible), but ahm, C is like almost at the equator and, but, if it is going around [gesture] it looks like has day and night, so wouldn't it be like, would D and C have almost equally as long days, except for E is like almost 24 hours? *I'm a little bit confused about that because C has a really long day and so does E.* *

T: And what about D?

*S8: D has like a longer day than B. But I don't know if it has a longer day than C. *It's really confusing.**

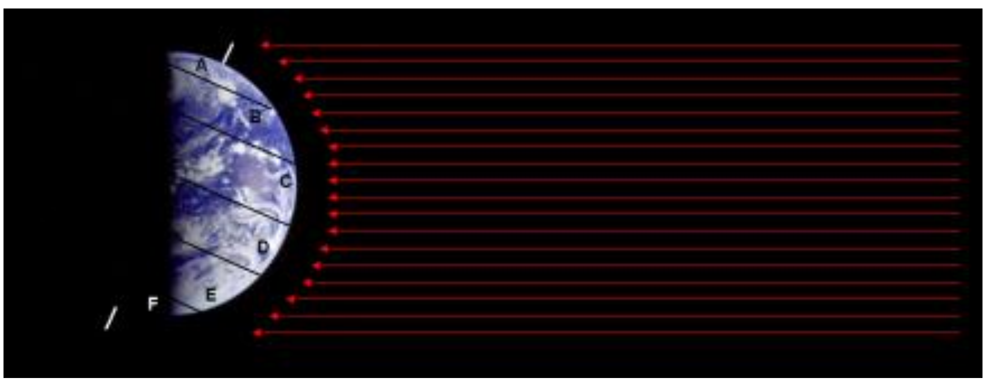
This is a *positive confusion*. The confusion was from the misconception that the place C would have the longest daytime because it was the furthest from the day-night line. This type of confusion is desirable in science classes and I believe teachers need to encourage students to experience this type of confusion, and help students resolve it with their abilities with minimal teacher intervention in classroom discussion. Teachers may ask students critical questions and guide the discussion without saying the correct concept at this stage.

The other type of confusion is when it disturbs the focus of the discussion by giving unnecessary and incorrect information. For example, in the intervention class 2 on day 15, described at page 109, some students were arguing where the equator line was and started to think that the place D in the below question was the equator. Before their discussion went off too far, the teacher correctly mentioned that the equator was placed between the place C and D. And another example is the below episode that took place on the day 17 in the intervention class 2.



Which do you think is the hottest place among the places of A, B, C, D, E, and F?

In the previous class, the students were discussing where the hottest place was. And the next day, the teacher showed the students the below diagram to clarify the concept. In the diagram, the red lines represent the sun rays, and some students recognized the angle between the sunrays and the earth surface as I had expected.



But interestingly, a few students started to focus on minor things on the diagram.

> T: Remember we talked about the angle between the ray of sun and the earth? S23 what do you think? Which place would you pick? [00:13:28.17]
>
> S23: C. [00:13:37.22]
>
> T: You'd pick C also? S35? [00:13:38.24]
>
> S35: I think B and D are equal. [00:13:42.16]
>
> T: You think B and D are equal? Would you be saying they'd be getting the same amount of sunlight, same type of rays in terms of angle? [00:13:46.21]

> S35: Yes, because if you look at it closely, *each slot there's four arrows each that go into it*, [went up to the computer] once they touch the earth, so *when you look at B, these four arrows right here, they are in the slot of where B is and same for D, where these four are.* [00:14:01.00]
>
> T: So now, which place do you think has the most direct sunlight? [00:14:48.23]
>
> S35: I still think it's D. [00:14:51.04]
>
> S27: If you see right here, *the D part of the area only gets about three of the arrows, but up at C, it gets about four of the arrows here,* and so does A, but C has more heat from the sunlight. [00:14:53.03]
>
> T: Ok, if we didn't even count the arrows, the number of arrows has nothing to do with it, just say, if we are looking at the area that gets the most direct sunlight. [00:15:24.16]

So in the quotes, S35 counted the number of sunrays that fell into each slot, and S27 started to consider the number of sunrays after hearing what S35 said. I would call this type of confusion is *unnecessary confusion.* When unnecessary confusion occurs, teachers should get rid of it and clarify it sooner before other students are contaminated by it, as what Mary did. It was wise that she clarified it as soon as possible before the discussion went off too far. Although I suggest broad meanings of positive confusion and unnecessary confusion, it needs more study to verify what makes the difference between positive confusion and unnecessary confusion and how they affect on student reasoning.

This study identified various student discourses while engaging in the classroom discussion. The developed discourse types may suggest possible interesting topics for future work. For example, the student discourse types may be useful to understand student-reasoning process. In Chapter 4.2, misconceptions about the length of daytime in different places on earth were described. As can be seen in Table 8, the student responses were different depending on whether or not *dynamic visual reasoning (dyVR)* was applied.

It shows the possible microanalysis of the relationship between student discourse types and their reasoning. Then, would a specific teacher questioning encourage students to engage in a specific discourse and that might affect their reasoning? What kind of teacher questioning would occur student *dynamic visual reasoning* or *dynamic visual spatial thinking*? This is also another interesting topic to investigate for future.

Previous literature has investigated various gestures as a clue to understand reasoning (e.g. Roth, 2003a, 2003b; Roth & Lawless, 2002). While conducting this study, I often witnessed student gestures that somewhat related to their discourses. For example, when the students engaged in *direct description* discourse, they did not show much gesture, while they often showed *pointing* when they engaged in *visual reasoning* discourse. In *visual spatial thinking* discourse, the students showed various hand movements. Especially, the students often showed *rotating* movement using their fingers when they engaged in *dynamic thinking*. Thus, investigating the relationship between the student discourses and their various gestures would tell us an important insight into the hidden reasoning process. Since those topics are beyond the scope of this study, they remain as future work.

Conclusion

In most traditional science classes, the pedagogical roles of photographs have been often disregarded. They have been considered as simply providing aesthetic beauty, or as supplementary information with captions on textbooks. Photographs have been less considered for the possibilities of various uses in enhancing student learning in class than other visual representations such as symbolics, animations, or simulations.

Photographs represent our lived world with rich details and are the most common visual representation that can be met easily in daily lives. People produce thousands, millions of photographs everyday, and they can be easily reached now with the development of the Internet. Why not using such abundant resources in science classes?

This study showed how similarly photographs in science classes could be used as in professional science research. Scientists observe objects or phenomena, often as the form of photographs especially in astronomy; bring a scientific question from the observation; interpret and analyze the photographs to understand why this happens; perform a scientific experiment or modeling a computer simulation to collect more data or to verify it; and finally draw a scientific conclusion. Therefore, in science research, photographs play more roles than just providing aesthetic beauty or drawing people's attention. Rather, photographs are treated as important data that represent phenomena or contain information in solving the scientific research question. In this study, photographs were presented to the students so they could observe objects and phenomena in the photographs. While the students were observing the photographs, they brought up various questions that could initiate interesting classroom discussion. When a concept development question was presented, they started to interpret and analyze the photographs to solve the question. While participating in the classroom discussion, the students developed reasoning about why it could happen. At the end of the discussion, they drew a conclusion.

In such process, the students engaged in various visual thinking discourse such as: *direct description, visual reasoning, visual spatial thinking, dynamic direct description, dynamic visual reasoning, dynamic visual spatial thinking, applying a scientific concept,* *connecting to experience*, and *imagination*. The teacher also engaged in various discourse: *requesting preliminary observation, provocative concept development question, reading off a histogram result, reasoning question, spontaneous guidance question, revealing an answer for the question, encouraging student participation in discussion, teacher clarification,* and *formative assessment meta-level communication*. The students and the teacher actively interacted to each other as seen in the student-teacher interaction model (Figure 17).

There were three important teacher questionings that made this flow happen: *what do you see?*, *what is happening?*, and *why do you think it happens?* The teacher guided the students to observe the photographs, by asking *"what do you see in the photo?*" Then the teacher presented a concept development question, asking the students to recognize "*what is happening?*" Finally, the teacher asked the students to think about "*why it happens*." Through the lessons, the *students generated* various ideas while the *teacher guided* them.

This study showed that the combination of using photographs and conceptual questions with the CRS technology encouraged the students to participate in discussion and helped the students develop their visual thinking, and as a result it enhanced student learning in astronomy. The students who participated in this study learned process skills such as how to listen to others' opinions and how to debate their own thoughts, as well as acquired content knowledge. The photographs helped the students feel comfortable with learning and most students thought that the new lessons were easy to learn. The photographs also helped the students articulate their daily experiences and connect them to the new scientific concepts. The photographs could show the evidence of unexpected events, playing a role of a discrepant question. This study showed that the photographs play more various pedagogical roles than had been traditionally thought and are useful pedagogical materials in classroom discussion in science class.

APPENDICES

APPENDIXA. ASTRONOMY CURRICULAR UNIT FOR THE CONCEPTS OF DAY-NIGHT AND CAUSE OF SEASONS

Day-Night cycle

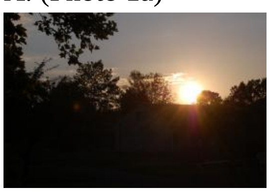
Introduction: Sunlight, Shadows, & Temperature

Concept goal: For students to realize the sunlight from their daily experiences.

There are two sub-concepts to discuss in class with below photographs; 1) Height of the sun vs. its shadow, and 2) Height of the sun vs. how warm we feel from the sun. When the sun is higher, it has smaller shadow. When the sun is lower, it has larger shadow. When the sun is higher, we feel hotter since earth surface gets more heat/area (higher intensity). <u>This concept will need to be returned when the concept of "cause of seasons" is covered.</u>

1. Show the following pictures to students. (Photo1)

A. (Photo 1a)



B. (Photo 1b)

CRS Q1. The both photos were taken at same place at same day. What time of the day do you think they were taken? Choose all that apply.

a) *Photo A was taken at sunrise or at sunset.*
b) *Photo A was taken at near noon.*
c) *Photo B was taken at sunrise or at sunset.*
d) *Photo B was taken at near noon.*
e) *None of the above.*

CRS Discussion1: How do you know? What was the reason that you chose that answer? What do you see a difference in those photos? [Discussion point: height of the sun vs. time of the day]

CRS Q2. Imagine that you were in the place when the photos were taken. Which one would you feel hotter?

a) *when photo A was taken*
b) *when photo B was taken*
c) *same at A & B*
d) *None of the above.*

CRS Discussion2: Why do you think so? What was the reason that you chose that answer? [Discussion point: height of the sun vs. the temperature, this concept should be returned later again when the concept of the causes of the seasons is covering.]

2. *CRS Q3. The below two photos were taken at same place at same day. What time of the day do you think they were taken? Choose all that apply.*

C (Photo 2c)

D. (Photo 2d)

a) Photo C was taken at dawn or at sunset.
b) Photo C was taken at noon.
c) Photo D was taken at dawn or at sunset.
d) Photo D was taken at noon.
e) None of the above.

CRS Discussion3: How do you know? What was the reason that you chose that answer? Where is the sun in photo C? How do you think the relationship between the height (angle) of the sun and the length of the shadow?

<u>If T thinks it is needed:</u> Let students draw the sun and the shadow to represent the above two photos. They will need to think about where to put the sun and how long the shadow should be. And, let them compare the two drawings, and think about the relationship between the angle of the sun and the length of the shadow, and why this happens. <u>[If they draw, I would like to collect the data.]</u>

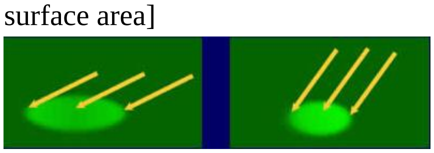
[Discussion point: length of shadow vs. angle of the sun, It's not important if the photo D was taken at sunrise or at sunset. The important thing is that it has longer shadow, and therefore the angle of the sun should be very small (in other words, the sun is at lower position.]

3. **Demonstration** (Hands-on activity): Prepare a lamp, a sphere and a stick.

Fix the lamp and face it one direction. The lamp represents the sun, so it should not be moved. Put the stick on the sphere. The stick represents the tree. The sphere represents the earth.

1) ***Activity 1****: Shine the stick with the light. Rotate the sphere slowly and observe the shadow of the stick.*

2) ***Activity 2****: Shine the sphere (where there is no stick). Rotate or move the sphere slowly and observe the size of the surface where the light is shined on. Discuss the angle of the sun and the size of the surface area.* [Discussion point: the angle of the sun vs. the size of the surface area]

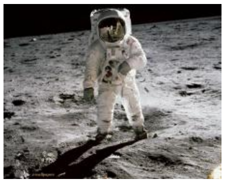


(ref1)

3) Discuss the above photos (A,B,C,D) with the demonstrations.

TJ mode: Different perspectives about day-night cycle
(Y. Schur, H. Pensso, & B. Schwarz, 2007; ESCALATE White paper)
[Students' survey: Please let students prepare a paper to do this activity. And, please make sure that they write their name on it. I'll collect their responses.]

1. Encounter with the moon environment: photo of the astronaut on the moon



(photo 3)

Imagine that you are the astronaut on the moon in the photo. Describe what you see around you. Please write down any questions that you have while thinking of yourself on the moon.

CRS Q. Is it day or night on the moon where you stand at the moment the photo is taken?

a) Day
b) Night
c) It depends.

CRS discussion: Why do you think so? What was the reason that you chose that answer? What were your questions while thinking of yourself on the moon?

[Discussion point: Some students may think it is night because it has dark sky. Let students think about where the sun is shining in the photograph.]

2. The earth observed from the moon

(photo 4)

What is this? Do you see on the photograph the day-night exchange on the earth? Please explain it. Please write down any questions that you have to answer the question.

CRS Q. Please choose a statement that describes the day-night cycle on the moon correctly as you observe it from your moon location.

a) Moon is night all the time. It doesn't have daytime.
b) Moon is day all the time. It doesn't have nighttime.
c) Day-night occurs every 24 (earth's) hours on the moon.
d) Day-night occurs every (earth's) month on the moon.
e) It depends where you are on the moon.
f) I don't know.

CRS discussion: Why do you think so? What was the reason that you chose that answer? How can you know the length of the day on the moon?

[Discussion point: Here the answer is d. One day of the moon is a month of the earth. Maybe it would be too difficult for students to understand why the moon has such a long day. The discussion might be enough for them to know that the moon has different length of the day from the earth.]

3. Experiencing a moon day as an astronaut (photo 5)

B. B.

Imagine that you are the astronaut in those photographs. Compare what you see on those two photographs. (Do you see differences of sun and shadows of you?)

CRS Q. Which photograph do you think was taken at nearer noon of the moon day

- *a) Photo A*
- *b) Photo B*
- *c) Photo A and Photo B were taken at same time of the moon day.*
- *d) It doesn't have enough information.*
- *e) I don't know.*

CRS discussion: Why do you think so? What was the reason why you chose that answer? [Discussion point: Here the answer is a. This question is similar from the earlier tree question (photo2). The difference is that this occurred on the moon. This is for students to notice the length of the shadows and the time of the day, and the principle is the same whether they are on the earth or on the moon.]

CRS Q. Let's look at the photo A. Do you think it will be night or day at the place where you are standing in two hours (in 12 hours, in 24 hours, 15 days, and 28 days)?

- *a) Day*
- *b) Night*
- *c) It depends.*

CRS discussion: Why do you think so? What was the reason that you chose that answer? [Discussion point: Again, this might be too difficult for 6 graders to understand why this happens if they don't understand the length of daytime on the moon. This question might be enough for them to notice that the moon also has day-night cycle, but it has different length of daytime than the earth.]

<u>*Students' Survey*</u>*: Please describe the whole day-night period as the astronaut on the moon experiences and relate it to the moving Sun in the sky of the moon. Please include scientific explanations.* <u>[Please let Ss write down this on their paper with their name, and I'll collect this data.]</u>

4. Coming back to the Earth: Write a story about their first day experience on the earth after coming back from the long trip to the moon.

Students' Survey:

[Please let Ss write down their stories on their paper with their name, and I'll collect this data.]

(photo 6)

1) Now you are back to the earth and land on the desert (photo 6). Please describe what you see and your first day experience on earth after such a long trip to the Moon. Please relate/compare your description to your experience on the moon.

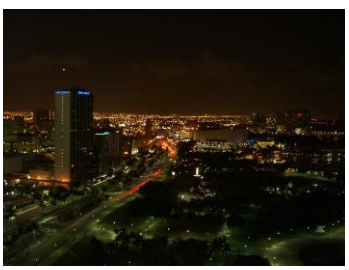
(photo 6-1)

2) What about if you land on this beautiful Caribbean beach. Please describe what you see and your first day experience on earth after such a long trip to the Moon. Please relate/compare your description to your experience on the moon.

(photo 6-2)

3) What about this place? Where do you think you land on?

The place you land on is south pole. Please describe what you see and your first day experience on earth after such a long trip to the Moon. Please relate/compare your description to your experience on the moon.



(photo 6-3)

4) What about here? This is the city near to the place where you land on. Please describe what you see and your first day experience on earth after such a long trip to the Moon. Please relate/compare your description to your experience on the moon.

[Discussion point: Read students' stories in class. It will be exciting to see their feelings of coming back to the earth. It enables the students to connect between their everyday experiences and language to that of the scientific terminology needed for writing the stories. This is a summative stage that students think about the day-night concept and about its different representations in different places.]

Concept goal: Direction of the rotational axis of the earth; West -> East

(photo 7) photo of the earth and the moon

Please describe what you see. What do you think they are?
Why do you think the earth and the moon look like half sphere? Where is the sun?

Small Group Discussion ***(Ss_handout1)***

(Photo 8) photo of the earth taken in space

What is this? Where is the sun? (This was taken from the front where the sun was shinning on it (imagine that you are the sun and looking at the earth) unlikely to the previous one.)
CRS Q: What time was Florida when this photograph was taken? [Teacher may need to point out where the Florida is on the photo.]

a) Dawn
b) Morning
c) Noon
d) Afternoon
e) Sunset
f) Night
g) It depends.

CRS Discussion: Why do you think so? How is the earth rotating?

[Discussion point: The purpose of this question is for students to recognize the rotation of the Earth and its direction. The answer for this question could be several if they have not talked about the direction of the rotation. Let students encourage talking first about how they think it. Majority of students may think that the earth is rotating from east to west since they have observed that the sun rises at east and sets at west. T may need to clarify this in the end of the discussion that the earth is rotating from west to east. (In the photograph, it moves from left to right, so the correct answer is d) afternoon.)]

Discussion: Which direction does the earth rotate? There are two truths that you may have experienced. 1) The sun rises in the East and sets in the West, and 2) It is always an earlier time in California (in the West) than it is in Massachusetts (in the East).
Discussion: How does the earth's rotation look like?

[When north is up, it looks to rotate counterclockwise, however from the southern hemisphere's view, it looks to rotate clockwise. Let students observe it with the globe.]

(photo 9) photo of the earth in space.

Q: This is the photo of the earth. There are 3 places (A, B, and C). What time was each place when the photo was taken? [Ask students for each place.]

a) Dawn
b) Morning
c) Noon
d) Afternoon
e) Sunset
f) Night
g) It depends.

CRS Discussion: Why do you think so?

Bridge to the Day-Night Cycle & Cause of the seasons

(Brainstorming) Open discussion: 1) What do you see the difference between in summer and in winter? 2) Would it be the same season in both northern and southern hemisphere?
[Discussion point: This is for students to start to think about concept of seasons. They may talk about different temperature, different nature, holidays, or even different length of daytime. Let students talk whatever they want to say relating to the seasons during the discussion.]

Concept of tilted axis of earth

Concept goal: 1) Earth rotates around its tilted axis.
2) The tilted rotational axis causes different length of day and night on earth.
3) The tilted axis causes the phenomena, polar darkness and white night, in both poles.

[Show students the following four photographs and share their ideas "shortly" as a whole group. After that, they will work as a small group to think about why these phenomena happen on earth.]

Polar Darkness

Photo 10: photo of Igloo with a polar bear in North Pole in December (winter in northern hemisphere)


(http://www.guy-sports.com/humor/videos/powerpoint_winter.htm)

10-1. (introducing the photo): *What do you see in this picture?*
Where do you think it was taken?
10-2. *CRS Q. This photo was taken in near North Pole in December. When do you think it was?*
a) At Noon
b) At Midnight
c) At Dawn or Sunset
[The answer could be anything since it is dark during 24 hours in North Pole in winter. The actual answer would be a, noon.]
CRS Discussion: Could it be daytime? Why or why not?
T Explanation: *This photo was taken at noon in December. It was very dark and the sun was almost near the horizon at around noon. This darkness is called "polar darkness." This happens during winter and it lasts until early March in North Pole.*

Photo 11. photo of emperor penguins in South Pole taken in June (winter in southern hemisphere)


(captured from Planet Earth)

11-1 (introducing the photo): *What do you see in this picture?*
Where do you think it was taken?
11-2. *CRS Q. This photo was taken in the South Pole in June. When do you think it was?*
a) At Noon
b) At Midnight
c) At Dawn or Sunset
[The answer could be anything since it is dark during 24 hours in South Pole in winter.]
CRS Discussion: Could it be daytime? Why or why not?
T Explanation: *This photo was taken in South Pole at noon in June. It is very dark and it is "polar darkness." Why do you think this polar darkness happens? Why do you think it is different that the polar darkness happens in December in North Pole and in June in South Pole?*
[They are just inquiry questions. Hear students' ideas shortly since they will have more time to discuss it later.]
T Explanation: *Polar darkness happens during the winter in both poles (north in Dec. and south in June). In southern hemisphere it is winter in June.)*

Midnight Sun (White Night)
Photo 12: photo of penguins in South Pole in December (summer in southern hemisphere)


(http://www.guy-sports.com/humor/videos/powerpoint_winter.htm)

12-1. (introducing the photo): *What do you see in this picture?*

Where do you think it was taken?

12-2. *CRS Q. This photo was taken in the South Pole in December. When do you think it was?*

a) At Noon
b) At Midnight
c) At Dawn or Sunset
d) All of the above.
e) It depends.

[The answer could be anything.]

CRS Discussion: Could it be nighttime? Why or why not?

T explanation: *This photo was taken in South Pole at 3am in December. Southern hemisphere is summer (when Northern hemisphere is winter) in December. The sun is above horizon for a long time and never sets during the summer. This is called "midnight sun" or "white night."*

Photo 13. photo of midnight sun in Norway (north of the polar circle) taken at 1am in June.


(http://flickr.com/photos/fotokurse-berlin/229333860/in/photostream/)

13-1 (introducing the photo): *What do you see in this picture?*

Where do you think it was taken?

13-2. *CRS Q: This photo was taken in Norway (where is the north of the polar circle) in June. When do you think it was?*

a) At Noon
b) At Midnight
c) At Dawn or Sunset
d) All of the above.
e) It depends.

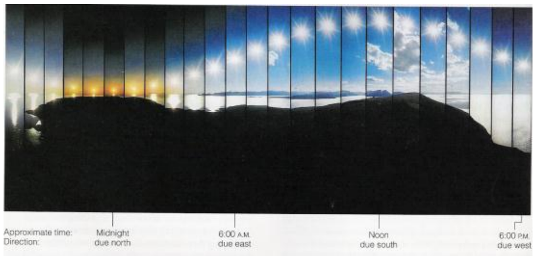
[The answer could be anything. The actual answer is b, midnight.]

CRS Discussion: Could it be nighttime? Why or why not?

T Explanation: *This photo was taken in Norway (where is the north of the polar circle) at 1am in June. The sun was still above the horizon in the midnight. It is also "Midnight Sun." Why do you think this happens? Why do you think it is different that the midnight sun happens in June in North Pole and in December in South Pole?*

[They are just inquiry questions. Hear students' ideas shortly since they will have more time to discuss it in the next.]

T Explanation: *Midnight Sun happens during the summer in both poles (north in June. and south in December). In southern hemisphere it is summer in December.*



Ref_image: Photo of the progression of the sun on the summer solstice (about 21,June) at the Arctic Circle

Small Group Activity:

Activity1: *Prepare a globe, a light bulb and a big paper to write for each group.* ***(Ss_handout2)*** *Shine the globe with the light bulb. Observe the globe by rotating itself and orbiting around the sun. Why do you think the phenomena, White Night (Midnight Sun) and Polar Darkness, happen on earth? Discuss it with your peers. Draw the earth and the sun and explain the phenomena with your group's consensus ideas.*

The concept goal for this activity: Rotational axis of the earth is tilted 23.5 degree from the (imaginary) vertical line which is perpendicular to the orbital plane.

[Let students work as a group of 2~3 students. After their work, let them to present their group's ideas to the whole class. After the class, I would like to collect their work.]

Activity2: Show the students the photo 14 and let them to discuss as a small group to answer the following CRS Q. (Ss_handout3)

Material: a globe, a paper and clickers for each group (individual Ss have their own clicker)


(photo 14)

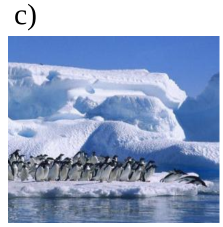
14-1. (introducing the photo, inquiry questions):

What do you see in this photo? How does the sun shine the earth in the photograph?

14-2. Q. *Which photo(s) of the below could be taken at the same time of the year when the above photo (photo 14) was taken? Choose all the apply.*

a)

b)

c)

d)


As a small group, discuss the question.

Give them a paper, so they can draw anything if that helps them think about this question.

14-3. CRS Vote. Students vote their answers to the clicker (as an individual).

Class discussion: Why do you think so? Why not the other photos?

(Some more probe questions for the discussion) What season do you think the southern hemisphere was when this photograph was taken? What about northern hemisphere? Why do you think so?

[Discussion point: The photo was taken by Apollo17, Dec. 1972. (Summer in southern hemisphere), and we can see the bright South Pole in the photograph. It never goes to the dark side when it is in the same time of the year. It keeps bright during 24 hours. Therefore, students may be able to induce that the South Pole experiences White Night and southern hemisphere is summer. On the other hand, northern hemisphere is winter and North Pole experiences polar darkness. Let students observe these phenomena by rotating and orbiting the tilted globe. T may need to help students to connect the phenomena (observed on earth) and the time of the year in orbit (real in space) through the demonstration and class discussion.]

Activity3: ***Show the students the photo 15 and let them to discuss as a small group to answer the following CRS Q.*** ***(Ss_handout3)***

Material: a globe, a paper and clickers for each group (individual Ss have their own clicker)


(photo 15)

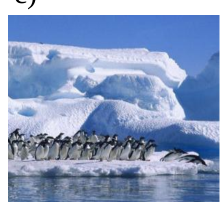
15-1. (introducing the photo, inquiry questions):

What do you see in this photo? How does the sun shine the earth in the photograph?

15-2. Q. *Which photo(s) of the below could be taken at the same time of the year when the above photo (photo 15) was taken? Choose all that apply.*

a)

b)

c)

d)


As a small group, discuss the question.

Give them a paper, so they can draw anything if that helps them think about this question.

15-3. *CRS Vote. Students vote their answers to the clicker (as an individual).*

Class discussion: Why do you think so? Why not the other photos?

(Some more probe questions for the discussion) What season do you think the northern hemisphere was when this photograph was taken? What about southern hemisphere? Why do you think so?

[Discussion point: In the photograph we can see the North Pole. It is in the bright side in the most of the day when rotating itself. Students may be able to induce that the North Pole experiences White Night and northern hemisphere is summer. On the other hand, southern hemisphere is winter and South Pole experiences polar darkness. Let students observe these phenomena by rotating and orbiting the tilted globe. T may need to help students to connect the phenomena (observed on earth) and the time of the year in orbit (real in space) through the demonstration and class discussion.]

Photo 16. *CRS Q: The below two photographs are the Earth taken in space in different seasons. On your paper, draw the earth and the imaginary line, rotational axis, before you answer the question. Observe the photographs carefully and choose all the statements that correctly describe.* (* skipped due to time limit)

A. (photo 16-1) *B. (photo 16-2)*

1) In photo A, North Pole experiences Polar darkness.
2) In photo A, North Pole experiences White Night.
3) In photo A, South Pole experiences Polar darkness.
4) In photo A, South Pole experiences White Night.
5) In photo B, North Pole experiences Polar darkness.
6) In photo B, North Pole experiences White Night.
7) In photo B, South Pole experiences Polar darkness.
8) In photo B, South Pole experiences White Night.
9) It depends.

Class discussion: Why do you think so? What was the reason why you chose that answer? How does your rotational axis look like?

[Discussion point: This question is for students to recognize the rotational axis of the earth. The tilted axis may be drawn in any direction depending on how they imagine observing the earth in space. This may confuse them that the axis may vary through the orbit. However, the axis never(*almost never in our lifetime)[2] moves or changes throughout the year because of the angular momentum. This is just from different view where to look at the earth. This can be easily performed in class with a tilted globe and let students look at it from one side and from the other side.
In this questions, some students may draw it as / (tilted from right-up to left-down) and some others do as \ (tilted from left-up to right-down). For the first case (drawn as /), the answers are 2, 3, 5, 8. For the second case (drawn as \), the answers are 1, 4, 6, 7. Explain that the reason why there could be two cases is just from our perspective, depending on how we see it. However, let them make sure that the direction of the rotational axis should not change through the years. **In the end, T will need to say this, "To avoid future confusion, let's use the first view (/) for the direction of the axis in this class!"**]

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[2] * There is a phenomenon called, Precession, which the rotational axis of the earth moves slowly like a wobbling top every 25800 years (well known as Platonic Year).

Concept of different length of daytime

Concept goal: Tilted axis of the earth causes different length of daytime.

(Brainstorming: Open discussion, Whole Class) *CRS Q: How have you experienced the time of sunrise and sunset change throughout the year in XXX, MA?*

a) It does not change. The sun rises and sets at the same time throughout the year.

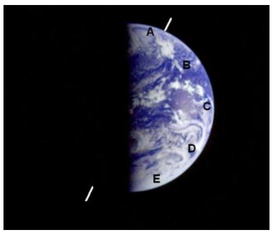
b) The sun rises earlier and sets later in summer than in winter.

c) The sun rises earlier and sets earlier in winter than in summer.

d) None of the above.

Class discussion: Why do you think so? What was the reason why you chose that answer?

Photo 17. ***(Ss_handout4)***



CRS Q 17-1: Compare the length of daytime for the place of A, B, C, D, and E.

a) The length of day time is the same for the place of A, B, C, D and E.

b) The length of day time is the longest at C, and then at B & D, is the shortest at A & E.

c) The length of day time is the longest at A, then B, then C, then D, and is the shortest at E.

d) The length of day time is the longest at E, then D, then C, then B, and is the shortest at A.

e) None of the above.

CRS Discussion: Why do you think so? What was the reason that you chose that answer? [Key: c]

CRS Q17-2: In the above photograph, what season do you think the Northern Hemisphere is?

a) Spring

b) Summer

c) Fall

d) Winter

CRS Discussion: Why do you think so? What was the reason that you chose that answer? [Key: b]

CRS Q17-3: In the above photograph, which place has the White Night?

a) A b) B c) C d) D e) E

CRS Discussion: Why do you think so? What was the reason that you chose that answer? [Key: a]

Photo 18. ***(Ss_handout4)***

CRS Q18-1. Please choose scientifically correct statement(s). Choose all that apply.

a) The place of A will be nighttime during 24 hours.
b) The place of B has shorter daytime than at the place of D.
c) The place of C has the longest daytime
d) The place of E will be daytime during 24 hours.

CRS Discussion: Why do you think so? What was the reason that you chose that answer? [Discussion point: Differently from photo 17, I didn't draw the rotational axis on the photograph. During the discussion, T may need to ask students' conceptions of rotational axis in this photograph. In other words, T needs to investigate how students draw the rotational axis in their mental images. When the rotational axis is assumed to be tilted from right-up to left-down, the answers for this question are a, b, d.]

CRS Q18-2. In the above photograph, what season do you think the Northern Hemisphere is?

a) Spring
b) Summer
c) Fall
d) Winter

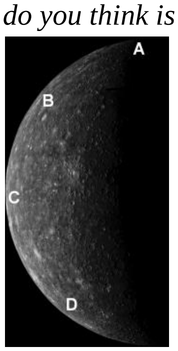
CRS Discussion: Why do you think so? What was the reason that you chose that answer? [Key: d]

CRS Q18-3: In the above photograph, which place has the Polar Darkness?

a) A b) B c) C d) D e) E

CRS Discussion: Why do you think so? What was the reason that you chose that answer? [Key: a]

Photo 19. *CRS Q. You have been observing a new planet. And, this is the photo of the planet. Where do you think is the longest daytime?* (* skipped due to time limit)



a) A
b) B
c) C
d) D
e) It depends.

CRS Discussion: Why do you think so? What was the reason that you chose that answer?
[Key: It depends on where the rotational axis is. Let students think about the rotational axis and its effect on the different length of daytime.]

Small Group Discussion: (Ss_handout5) After the above discussion (about the CRS histogram results), T spread the Ss_handout5 to the students. Let them discuss it as a small group. Let them present their group's results. **<u>Please do not show them the above photo.</u>**

(Closure) T's clarification: concept of tilted axis and different length of daytime

Cause of the seasons

[Make sure that students already learn the concepts of rotation and revolution of the earth, orbit of the earth, tilted axis of the earth, and the concept that the axis is always pointed in the same direction.]

<u>1. Checking Prior Conception</u> ***(Ss_handout5)***

Open Discussion: "What is the reason why the earth has the season?
(Why do you think it is hot in summer, and it is cold in winter?)"
[Discussion point: This discussion is for students to brainstorm about the cause of the seasons by themselves through whole class discussion. Let them just to think, talk, and share their ideas with classmates. Do not say a right answer at this point since this question will go along until the end of unit.
Maybe, the instructor can make a list by summarizing what they are saying, (and let students to vote through CRS). I assume majority of students will answer that the distance between the earth and the sun is the cause of the seasons. Then, this discussion can be naturally continued to the next.]

Small Group Discussion: Imagine that you just come inside from a severely cold weather, and you found a heater. How would you do to get more heat on your hand from the heater? Find three factors that may affect to raise the temperature on the surface of your hand from the heater. Discuss it with your peers.
[Encourage students to find out the most important three factors to decide the amount of the heat which is receiving from the heater to their hands; Angle of the surface (of the hands), Distance, and Time duration. For example, asking them;

1) Where do you want to be? -> To get close to the heater as much as possible. (Distance)
2) How do you want to put your hands? -> To be perpendicular to the heat. (Angle)
3) How long do you want to be? -> Stay as long as possible. (Time duration)]

Focus of the discussion: "Distance" to the Sun would affect the seasons on earth?

<u>2. Suspecting a strong prior conception (misconception about distance)</u> ***(Ss_handout5)***

[Majority of students have the misconception that the season on earth is caused by the different distance between the earth and the sun. This misconception is very resistant to change. The instructor will need to do the following two activities for students to suspect their prior misconception.]

2-1. (Small group discussion) *Show students the powerpoint images and let them observe the orbit of the earth around the Sun. And, let them talk about how the difference of the distances between closest and furthest is small.*

Ref: The earth is revolving the sun. The orbit is not an exact circle, but a rather oval shape. The distance between the earth and the sun is;

<u>Closest</u>: 147,093,602 km (<u>January</u>) => 147mm

<u>Furthest</u>: 152,097,053 km (<u>July</u>) => 152 mm

therefore, the difference: 5,003,451 km (only 3.3%) => 5mm

(radius of the sun: 695, 500 km => 0.7 mm, almost point source)

(radius of the sun: 6,400 km => 0.006 mm, almost point source)

→ Emphasize that it is a very small and tiny difference, and it is negligible.

But, I think that students may have not completely overcome the misconception yet.

2-2. (Discrepant event; Tsai & Chang, 2005) *As a small group, let students discuss the questions related to the two facts.*

Fact1: When America (northern hemisphere) is summer, Australia (southern hemisphere) is winter.

When America (northern hemisphere) is winter, Australia (southern hemisphere) is summer.

(Students may know the fact that Australia has warm Christmas (summer) in Dec.)

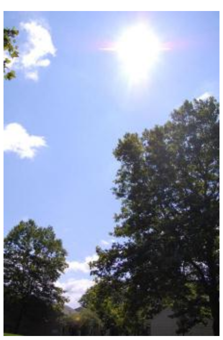
Fact2: The earth is closest to the sun in January, and is furthest in July.

Discrepant Event Discussion: If the season is caused by the distance, both northern and southern hemisphere should have the same season. In other words, the whole earth has to be summer in January, and to be winter in July. But, students know that this is not true from their experience and from previous unit (day-night cycle). Then, discuss "what is the reason for the seasons?"

<u>3. Building a new Conception: Angle of the surface</u> ***(Ss_handout5)***

Class discussion: (Photo 20) Photos of summer sun and winter sun

A. Summer Sun B. Winter Sun



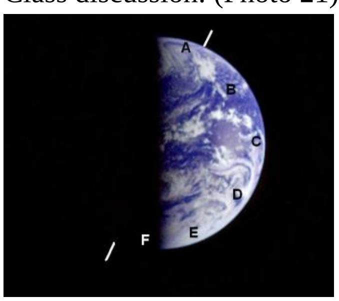

20-1. (Show students photo A.) *What do you see in this photo?*
When do you think this photo was taken? (let's say 1pm in July)

How do you feel the temperature from this photo? Is it cold? Or is it hot? Why do you think you feel that way?
How do you think the length of the day when this photo was taken?
How is the height of the sun in the sky?
20-2. (Show students photo B.) *What do you see in this photo?*
When do you think this photo was taken? (let's say 1pm in January)
How do you feel the temperature from this photo? Is it cold? Or is it hot? Why do you think you feel that way?
How do you think the length of the day when this photo was taken?
How is the height of the sun in the sky?
20-3. *Photo A was taken in July and photo B was taken in January. Both photos were taken at same time of the day (1pm) at the same place (nearby). What do you see the difference between A and B?*
20-4. *How do you think the height of the sun (in other word, <u>angle of the sunlight</u>) would affect the temperature in different seasons?*
20-5. *Please draw the earth and the sun seen in space. Please explain with your drawing when and how you could see the sun like the above photos. Discuss it with your peers.*

[Discussion point: T will need to encourage students to connect 'the concept of the height of the sun in different seasons' to 'the concept of the height of the sun in different time of the day (which has been seen in the first class)'. Students need to understand through the discussion that both concepts are based on the same principle which is the angle of the sunlight.]

<u>4. Building a new Conception: Revisiting the concept of different length of daytime</u>*(Ss_handout6)*

Class discussion: (Photo 21) photo of the earth and its tilted axis



21-1. What do you see from this picture? Where do you think is the sun?
21-2. Where do you think is the hottest place among the place of A,B,C,D,E, and F? Why?
[T can do this as CRS Q.]
21-3. Where do you think has the longest daytime?
[T can do this as CRS Q]
21-4. Why do you think the answer for 21-2 and the answer for 21-3 are different?
21-5. How do you think the temperature and the length of daytime affect differently between northern and southern hemisphere?

<u>★ This discussion is very important, maybe the most important part in the whole lessons.</u>

The place of C has the most direct sunlight than other places. In general, northern hemisphere (A,B, & C) has more direct sunlight than southern hemisphere (D, E, & F) (for example, C>D, B>E, A>F). And, northern hemisphere has much longer daytime than southern hemisphere. Therefore, northern hemisphere experience hot and long days which is summer, and southern hemisphere experience cold and short days which is winter. The key points for this discussion are that the two factors (temperatures caused by the angle of the surface and the length of daytime) affect the seasons on earth, and those factors are caused by the tilted axis of the earth. In other words, the seasons on earth is caused by the tilted rotational axis.

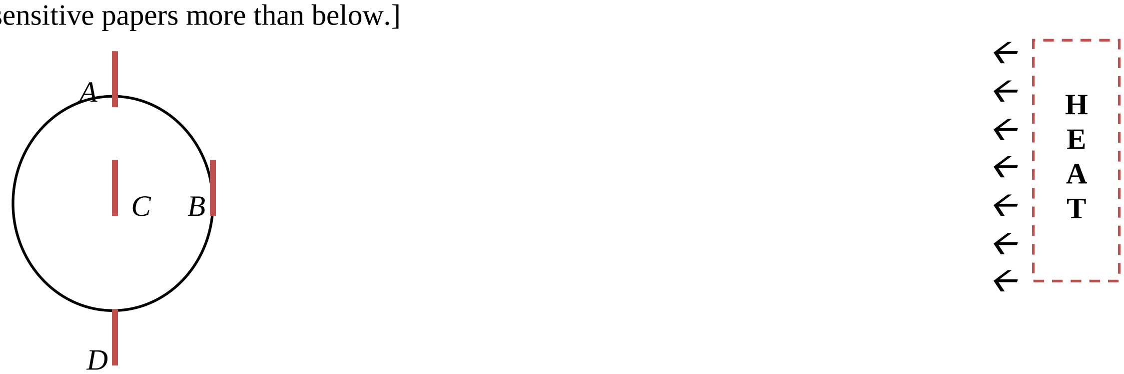
5. Demonstration: Concept of Angle (*This activity was skipped due to the limited time and uncertainty of the concept.)

[In previous 21-2, some students still might say that it is because of the distance. We will do the demonstration to clear it up.]
Prepare a heater and a ball attached with heat sensitive papers.

Activity1: The papers are attached on the surface of the ball.
CRS Q: *Let students to predict which would change the color at first.* [Put more heat sensitive papers more than below.]

[This question can be performed as a CRS Q such as:
A, B, C,…
It changes color at the same time.]
Class discussion: Why you think so? Why you chose that answer?
Demonstration (or small group activity): Turn on the heater and observe the color of the papers.
Class discussion: What happened? Why do you think this happened?

Activity2: All the papers are attached vertically onto the surface of the ball.
CRS Q: *Let students to predict which would change the color at first.* [Can put more heat sensitive papers more than below.]



[This question can be also performed as a CRS Q such as:

A, B, C, …

It changes color at the same time.]

Class discussion: Why you think so? Why you chose that answer?

Demonstration (or small group activity): Turn on the heater and observe the color of the papers.

Class discussion: What happened? Why do you think this happened?

<u>6. Clarification</u>(Small group discussion) ***(Ss_handout6)***

Draw the Earth, the Sun, and the orbit of the earth around the Sun. Mark the rotational axis of the Earth on the Earth. Please mark summer and winter for northern and southern hemisphere. Please explain what causes the seasons with your drawing. Discuss it with your peers and write (and draw) your explanation for the cause of seasons.

CRS Q. (conceptual): What do you think causes the seasons on Earth? Choose all that apply.

a) It is caused by the different distance between the sun and the earth.
b) It is caused by the different angle of the earth surface that receives the sunlight.
c) It is caused by the different length of daytime that the earth surface is exposed to the sun.
d) The tilted axis of the earth causes the seasons.

[Discussion point: tilted axis of the earth => angle of the surface & different length of daytime => cause of the seasons, Key) b, c, d]

<u>7. Application</u>

CRS Q. You have found that Mars has seasons as the way the Earth has it. What do you know from that?

a) The distance to the sun changes between seasons.
b) Mars has tilted rotational axis.
c) There is a planet that blocks the sunlight onto the Mars.
d) Mars has moons.
e) *None of the above.*

Class discussion: Why do you think so?

[Key) b]

Class Discussion: What if the rotational axis of the Earth is not tilted but straight up and down to its orbital plane? What would happen to the day-night cycle and seasons on Earth?
(Ss_handout6)

APPENDIX B. STUDENT WORKSHEETS

Student Worksheet 1

Earth's rotation and Day-Night cycle

Materials: a globe

1. Find the United States. The United States is located on the upper half of the Earth. This is known as the ______________________________. The lower half of the Earth from the Equator down is the ______________________________________.

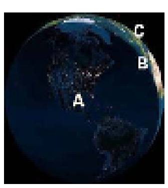
2. The Earth rotates around its imaginary line called a(n) ________________ every 24 hours. And, the direction of the ______________________ does not change its position throughout the year*.

3. Rotate the globe slowly. Which direction does the earth rotate? You may find some clues from your experiences; 1) The sun rises in the East and sets in the West, and 2) It is always an earlier time in California (in the West) than it is in Massachusetts (in the East).
The earth rotates from ___________ to ___________.

4. The rotation of the Earth is looked (clockwise Or counterclockwise?) in the Northern hemisphere, and (clockwise Or counterclockwise?) in the Southern hemisphere.

5. Rotate the globe slowly and observe it to answer the following questions.
5-1) Find the place of Florida in the below photograph. What time do you think Florida was when this photograph was taken? Choose one from sunrise, morning, noon, afternoon, sunset, midnight.

5-2) There are 3 places, A, B, and C. What time do you think each place was when the photo was taken? Choose one from sunrise, morning, noon, afternoon, sunset, midnight.

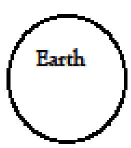


A:

B:

C:

5-3) How did you think that the earth rotates in the above photos to answer the questions? Draw the arrow to represent the direction of the rotation on earth and mark the place for north and south on the Earth.

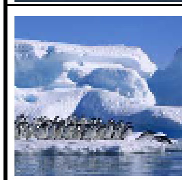
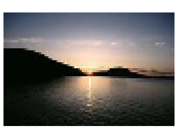


Student Worksheet 2

Polar Darkness and White Night

Polar regions experience very strange day-night cycle. During the winter, the sun never rises up above and mostly stays below the horizon or just near the horizon. This happens about 179 days at the Poles! So, if you go to the poles in winter, you will experience dark days for a long time. This phenomenon is called Polar Darkness. On the other hand, during the summer, the sun never sets and stays above the horizon for a long time (about 186 days at the Poles). This is called White Night or Midnight Sun. So, if you go to the poles in summer, you will not experience dark night. Remember! It is summer in northern hemisphere but winter in southern hemisphere in around June. And, it is winter in northern hemisphere but summer in southern hemisphere in around December.

1. Fill in the box.

Photo	Photo information	Season	Phenomenon
	North Pole At noon in December		
	South Pole At noon in June		
	South Pole At 3 am in December		
	Norway (North of the Polar Circle) At 1 am in June		

2. Why do you think Polar Darkness and White Night happen on Earth? Discuss it with your group. Make it a drawing if that helps your understanding. Write (with the drawing) your group's explanation on the big paper.

Student Worksheet 3

Polar Darkness and White Night

1. This is a photo of the Earth taken in space.

Which photos of the below could be taken at the same time of the year when the left photo was taken? Choose all that apply.

a)

b)

c)

d)

2. This is a photo of the Earth taken in space.

Which photos of the below could be taken at the same time of the year when the left photo was taken? Choose all that apply.

a)

b)

c)

d)

3. What do you see the difference of the Earth between photo 1 and photo 2? Where is the Sun? What seasons could it be?

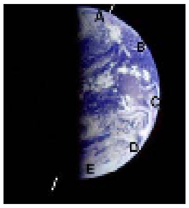
	Northern hemisphere	Southern hemisphere
Photo 1		
Photo 2		

Why do you think the Earth look different? Why do you think the phenomena, Polar Darkness and White Night, happen in the different seasons at the Poles on Earth? Make it a drawing if that helps your understanding. Discuss it with your group, and write (with the drawing) your group's explanation on the big paper.

Student Worksheet 4

Tilted Rotational Axis and Different Length of Daytime

1. This is the photo of the Earth taken in Space.

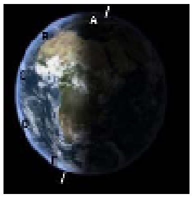


1) Compare the length of daytime for the place of A, B, C, D, and E.

2) In the above photograph, which place has the White Night?

3) Can we know the season on Earth from this photo? If so, what is it in the northern hemisphere?

2. This is the photo of the Earth taken in Space.



1) Compare the length of daytime for the place of A, B, C, D, and E.

2) In the above photograph, which place has the Polar Darkness?

3) Can we know the season on Earth from this photo? If so, what is it in the northern hemisphere?

3. Compare the length of daytime for place B in photo 1 and photo 2.

Student Worksheet 5

Cause of Seasons on Earth 1

1. What causes seasons on Earth? Write down your ideas in one or two sentences.

2. Imagine that you just come inside from a severely cold weather and you found a heater. How would you do to get more heat on your hand from the heater? Write down the most important three factors that you think may cause a rise in the temperature on the surface of your hand from the heater.

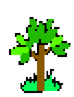
3. a. How do you think the shape of the Earth's orbit[1] look like? Draw it. How do you think 'distance' to the Sun would affect the seasons on Earth?

b. What can we know from the below facts? How do you think 'distance' to the Sun would affect the seasons on Earth?

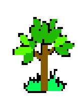
- When America (northern hemisphere) is summer, Australia (southern hemisphere) is winter.
- When America (northern hemisphere) is winter, Australia (southern hemisphere) is summer.
- The earth is closest to the sun in January, and is furthest in July.
- America is summer in July and winter in January.
- Australia is summer in January and winter in July.

4. How would be the shape of the path of the sun in our sky look like during the daytime in summer in Massachusetts? What does it look like in winter in Massachusetts? a. Please draw the path of the sun and the shadow of the tree at noon time in the below. Compare your drawings between summer and winter.

Summer | Winter



Horizon



Horizon

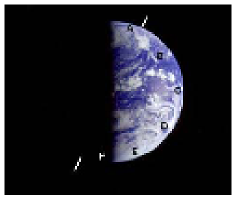
b. How do you think this affects the temperature on the Earth surface in different seasons?

[1] Earth's Orbit: the path of the Earth that revolves around the sun. One revolution of the Earth around the sun is 365.25 days.

Student Worksheet 6

Cause of Seasons on Earth 2

1. This is the photo of the Earth looked in space with the mark of the imaginary rotational axis.

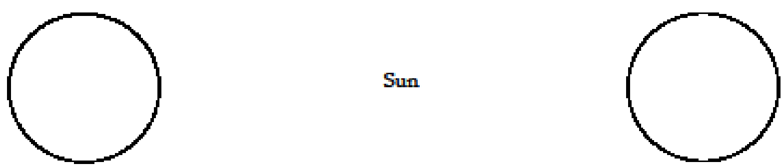


a. Where do you think is the hottest place among the places A, B, C, D, E, and F? And, why?

b. Where do you think has the longest daytime? And, why?

c. How do you think the temperature and the length of daytime compare between northern and southern hemisphere? And, what do you think causes these differences?

2. Please draw the Earth for the two different times of the year, July and January. In the below diagram, mark the line for equator and for the rotational axis of the Earth, and write summer and winter for northern and southern hemisphere. And, mark if it is either July or January.



Please explain <u>what causes the seasons on Earth</u> with the diagram.

3. <u>What if</u> the rotational axis of the Earth is not tilted but straight up and down to its orbital plane? What would happen to the day-night cycle and seasons on Earth?

APPENDIX C. INSTRUMENT

Appendix C.1: Student Conception Survey (pre- and post-tests)

1. What is your definition of ‘day (daytime)’ and ‘night (nighttime)’?

2. Why do you think day and night happen on Earth?

3. Do you think different places on the earth have different lengths of daytime? Why or why not?

4. How does the time of sunrise and sunset change throughout the year in Westfield, MA, and why?

5. What do you think causes the seasons?

6. Please draw the earth and the sun for summer and winter. Explain the causes of the seasons with your drawing. Please use the backside if you need more space.

7. Suppose you have found an unknown planet when you are observing the night sky (How exciting!).
7-1) Does the planet have day and night? Why or why not?

7-2) Does the planet have the different length of daytime? Why or why not?

7-3) Does the planet have seasons? Why or why not?

7-4) Please draw the sun and the planet, and mark the rotational axis of the planet. Explain for the question 7-2) and 7-3). Please use the backside if you need more space.

Appendix C.2: Student Attitudes Survey

In the past few weeks, you have learned astronomy concepts, *day-night* and *cause of seasons*, with photographs and using clickers. This survey is to understand how you have felt about it in your class. Please answer the following questions as best as you can. Thank you.

Name:___________________________________
I'm a: Boy ( ) Girl ( )

1. Please mark for the following questions.

This is my first astronomy class in school.	Yes ( )	No ( )
I have been to an astronomy camp.	Yes ( )	No ( )
I have been to a science museum.	Yes ( )	No ( )
I'm interested in astronomy.	Yes ( )	No ( )
Astronomy is my favorite subject.	Yes ( )	No ( )

2. In general, how have you felt about the degree of difficulty of this lesson?

Very difficult	Difficult	I don't know	Easy	Very Easy
○	○	○	○	○

3. Please mark in the below boxes for the following questions about your experiences of learning astronomy in this class.

	Strongly, No.	No	I don't know.	Yes	Strongly, Yes.
It was a lot of fun to use clickers in class.					
I hope my teacher keeps using the clickers.					
The use of clickers made me more interested in learning astronomy.					
I really liked to see the photographs in class.					
I hope my teacher keeps using photographs in astronomy class.					
The photographs made me more interested in learning astronomy.					
The photographs made me think a lot about astronomy concepts.					
The photographs confused me about astronomy concepts.					
The photographs helped me to learn astronomy better.					
The photographs helped me to notice scientific phenomena around me.					
The photographs help me to learn different views about the concepts.					

I felt more involved in this class than my other classes.					
Seeing photographs helped me pay more attention in class.					
Photographs gave me ideas, so I could easily participate in class discussion.					
Listening to other student opinions helped me learn astronomy.					
It was interesting to hear other student ideas.					
I don't see the value of discussion with peers, it just made me confuse.					
The lessons with the photographs made me think more about things that happen around me.					
In general, my observation skill has been improved since completing this unit with the photographs.					
I found observing scientific events more often and in more detail since completing this unit with the photographs than before.					

4. In general, how have you felt about learning astronomy with the photographs and the use of clickers?

5. How do you think the photographs helped you to learn the concepts, day-night and cause of seasons in this class?

6. Is there anything that you specifically liked or disliked when you learned astronomy with the photographs in this lesson? What was it and why?

7. How do you think the discussion with your classmates helped you to learn astronomy?

8. In the lesson about polar darkness and white night, you have seen the 4 photographs taken at different times of the year at the North Pole and at the South Pole (for example, the photos of the Igloo and the penguins, etc.). You also saw the photographs of the Earth taken in space at different times of the year. How do you think those photographs helped you learn the concepts, polar darkness/ white night and different length of daytime in different places on Earth?

9. Any other additional thoughts or comments for this lesson?

Thank you. ☺

Appendix C.3: Teacher Interview Questionnaire

Pre-interview

1. How long have you been teaching astronomy?
2. Can you tell me how you used to teach the
    1) Concept of day-night
    2) Concept of cause of seasons
3. How did you feel the lessons went? (Try to find out their feelings about their teaching and their students' learning.)
    1) Concept of day-night
    2) Concept of cause of seasons

    (Did your students seem to understand the concepts well?)
4. What challenges did you have when you were teaching this unit in the past?
5. Please describe a good science teacher – what should the teacher know and be able to do?

    Probes: what is the significance of the following aspects for a good science teacher?
    - students' knowledge
    - curriculum knowledge
    - knowledge of assessment
    - knowledge of instructional methods
6. Please describe a typical discussion in your class. Please explain how you conduct it. Is there anything that you would like to change? (Provide time between these three questions for the teacher to answer each part).

    Probes:
    - What is the same or similar between all your class discussions?
    - What dffers from discussion to discussion?
    - Does every student participate or just specific students only?
    - What is the relative time that you talk in a discussion compared to your students?

- Do you have specific ways you use to encourage students to participate, to get higher level questions and answers, or to create a comfortable atmosphere in class?

7. When participating in PD, what is most important for you? What are the main characteristics of good PD?
8. How do you usually use questions in your classes?

   Probes:

   - What is the purpose of asking questions?
   - What is the typical “waiting time” after you ask a question?
   - Who is asking most of the questions? (the teacher, many or few students)
9. Is there anything that you would like to add?

Mid-interview

1. How did you feel the lessons went for the last few days? (Try to find out her feelings about her teaching and her students' learning.)
   - What do you think went well? Why?
   - What do you think didn’t go well? Why?
   - Do you think they seemed to understand the concept that learned for the last few days?
2. What challenges did you have when you were teaching the lesson?
3. How do you think students’ reaction to the photographs shown for the last few days?
   - Do you think the photographs gave them more confusion and may generate misconception?
   - Is there anything that you observed a positive potential of using photographs for your students to learn science better from the last few days’ lesson? If so, what was it, and why?
4. How did you feel about class discussion for the last few days?

- How did you feel about using photographs to encourage class discussion? Do you think it was helpful, or not helpful? Why?

5. If you want to modify the last few days' lesson, where is it and how you want to change it? And, why?
6. Any more thoughts for positive and negative experiences using photographs for the last few days?

Post-interview

1. How did you feel the lessons went? (Try to find out their feelings about their teaching and their students' learning.)
   (Did they seem to understand the concepts well?)
2. Were you satisfied using the lesson (that I had developed) for this unit? Why or why not?
3. What has changed compared to the way you were teaching this lesson previously?
4. What was good about using the photographs?
   Probes:
   - How did students react to the photos?
   - Was there anything you were not able to teach without the photos?
5. Was there anything negative about using the photographs?
6. What effects do you think the uses of photographs had on students' participation in discussion?
   How do you feel about using photographs to encourage class discussion in your class?
7. What challenges did you have when you were teaching this unit with these materials?
   What was the highlight of using photographs? What stands out specifically positive?
   (Any specific example of positive experience?)
8. Please describe a good science teacher – what should the teacher know and be able to do?

Add to previous probes:

- Have you changed your view of a good science teacher after teaching the unit?

9. Please describe the discussions in your class. Please explain how you facilitate a discussion..

   Add to previous probes:

   - Has anything changed in the way you facilitate class discussions in this unit?
   - Has anything changed in the way your students participate in discussions in this unit?

10. What (if anything) has changed in the way you and your students used questions in this unit?
11. If I plan to design PD with this kind of lesson, what do you want to say to me? Any suggestions or comments?
12. Is there anything that you would like to add?

APPENDIX D. SEATING CHARTS

Intervention Class 1

12 boys (B) and 6 girls (G): total 18 students

B: S1
B: S2
G: S11
B: S6
B: S15

B: S4	G: S3
G: S17	B: S9
B: S14	G: S5

B: S13	B: S18

B: S12
G: S7
G: S8
B: S10
B: S16

Intervention Class 2

9 boys (B) and 9 girls (G): total 18 students

G: S21
B: S22
B: S23
B: S24
B: S25

B: S26	G: S29
B: S27	B: S30
G: S28	G: S31

G: S21	G: S32

G: S33
B: S34
B: S35
G: S36
G: S37
G: S38

APPENDIX E. SUMMARY OF VIDEORECORDINGS

Intervention class 1		
Day	Video Time/ Class Description	Transcribed Minutes
1	22:20 – 45:00 photo, CRS Qs, WCD	23
2	26:00 – 40:00 photo, CRS Qs, WCD	15
3	08:00 - 19:02 T's explanation, some WCD 22:00 - 39:15 small group discussion, CRS Qs, WCD	11 17
4	04:20 - 07:35 Definition of day/night (Ss read their writing.) 12:10 - 15:00 Ss writing (no need transcription) 15:10 - 19:00 WCD (Ss read their writing, sharing their ideas) 19:00 - 20:30 Ss' writing (Qs being on the moon) 20:30 - 42:30 CRS Qs, WCD	3 - 4 - 22
5	6:00 – 35:00 WCD, photo, CRS Qs 36:00 – 45:00 writing	29 -
6	02:30 - 06:10 Ss read their TJ stories. 07:10 - 13:00 photo description 17:00 - small group discussion (S6's group, no discussion) 26:20 - 32:00 small group discussion (S1's group) 34:00 -43:25 T review (checking the answers quickly, T's explanation, no discussion)	- 6 - 6 10
7	03:00 -44:00 CRS Q, WCD	41
8	03:45 -37:30 photo, WCD (polar darkness/white night photos, CRS Qs) 40:00 - 45:30 small group work (simple Q)	34 -
9	03:00 - 13:00 T talks (short explanation, instruction for a small group work) 13:00 – 40:30 small group work (S1's group) ** (18:00-20:00 day/night pattern *)	- 30

10	09:00 - 45:00 small group work & presenting **	36
11	04:00 - 10:10 small group presenting (good discussion about the way they drew) * 17:00 - 40:00 small group discussion, WCD ***	6 23
12	09:40 – 15:00 checking 20:00 – 41:00 WCD, CRS Q	- 21
13	04:00 – 44:00 WCD ***	40
14	03:30 – 07:20 WCD 08:40 – 11:40 vote for CRS Q 11:40 – 43:50 WCD	4 - 32
15	03:00 - 11:15 WCD 11:30 – 18:30 Ss read their writings about cause of seasons 18:30 - 19:10 T's classification of Ss' answers 23:00 - 25:40 WCD (factors that raise the temperature of hands from a heater) 25:40 - 44:45 Discussion about distance	8 - (0:40) 3 (2:40) 19
16	01:50 – 19:20 photos, WCD 23:00 – 30:10 small group discussion (S1's group) 32:20 – 34:00 small group discussion (S11 - Teacher talks) 34:00 – 37:32 small group discussion (S15's group) * 37:32 – 42:50 WCD (each group represents their answer, S8 & S6 went up to the front to explain it with the photo)*	18 7 2 9 (3:30) (5:30)
17	02:50 T's direction about Q2 04:30 – 41:10 mostly small group discussion (mostly S1's group)	- 37
18	Entire: WCD & CRS Q	43
19	01:45-15:30 WCD	14

Intervention class 2		
Day	Video Time/ Class Description	Transcribed Minutes
1	25:00 – 45:00 photo, CRS Qs, WCD	20
2	06:40 – 26:00 photo, CRS Qs, WCD	20
	31:00 – 34:00 CRS Q	3
	44:00 – 48:00 CRS Q	4
3	03:30 - 12:20 T's explanation & WCD (Angle of the sunlight)	9
	15:00 - 21:30 WCD	6
	32:00 - 42:00 CRS Q, WCD	10
4	11:00 - 48:10 CRS Qs, WCD	37
5	02:30 - 04:20 T's clarification	2
	04:20 - 16:40 Ss writing down their stories, & sharing it.	-
	19:00 - 25:10 Some Ss' Qs (astronaut, moon, etc.)	6
	25:10 - 37:50 Ss' writing & reading TJ stories	-
	37:50 -46:10 WCD	9
6	10:00 -13:30 small group discussion (S35 & S36 group)	-
	13:30 -17:20 small group discussion (S24 & S28 group)	4
	17:30 - 30:30 small group discussion (S27's group) **	3
	30:30 - 40:00 T review (checking the answers quickly, T's explanation) (?)	18 (9:30)
	40:00 - 48:40 CRS Q, WCD	(8:40)
7	06:17 – 10:00 photo 9, Q9 (T's explanation)	4
	15:55 – 23:17 photo 10	8
	24:10- 32:40 WCD (CRS Q10, polar darkness)	8
	36:00 – 46:26 WCD (WCD, photo 11) – S24's gesture (at the end)	10
8	03:00 – 04:46 review yesterday (photo 10 & photo 11)	4
	04:47 – 06:00 photo 12	2
	07:00 – 12:00 WCD (photo 12, histogram, CRS Q, midnight sun)	5

	14:20 – 16:15 photo 13 18:00 – 23:15 WCD (photo 13, CRS Q) 30:00 – 45:00 small group work (the reason why it happens) (Ss-handout 2) => observe if the students ever mention what they saw in the photographs during the small group discussion**	2 5 -
9	05:00 – 09:30 T talks (progression of midnight sun) 15:00 – 46:00 small group work (Jason group)	- -
10	16:20 – 27:30 small group work (S28's group) (mostly just drawing and writing) 29:30 – 38:50 small group presentation (29:30 – 32:10 group 1, poor recording) (32:30 - 34:30 group 2) (34:30 – 36:30 group 3*) (35:30 poster) (36:30 – 38:50 group 4) (37:00 poster)	- -
11 *	13:20 – 25:00 T checks the answer & explanation (T's confusion) 25:00 –38:30 Small group discussion (handout 3, photo, S28's group, S24***) *** 38:00 – 47:00 T's checks, WCD	- 18:30 9
12 *	01:00 – 06:30 T's check (mostly T's talks) 11:30 – 24:00 WCD (histogram, photo 15 CRS Q) 34:00 – 44:00 WCD (CRS Q)	5:30 12:30 10
13 *	04:00 – 07:00 small group discussion (CRS Q 17-1) * 08:10 – 46:00 WCD (several CRS Qs) ** (12:10 S24's gesture)	3 38
14	08:10 – 11:30 Ss' read their written work for the seasonal cause and T summarized it. 22:15 – 39:40 WCD (mostly T talks) (Discrepant event) 39:40 – 48:00 WCD (photo 20, summer sun & winter sun)	- 17:30 8:20
15 *	03:50 – 12:40 WCD 12:40 – 17:30 T talks (diagram shown) 21:00 – 46:00 small group discussion (S27 & S35 group, argument) ****	9 5 25

16 *	Entire: Small group discussion & WCD ****	49
17	02:30 – 20:00 WCD 20:00 -24:00 Ss drawing the angle of the sun 24:00 -28:00T talks (Ref image) 28:00 – 32 :00 WCD T checks 37 :00 – 49:00 small group discussion (Ss_handout 6) (42:00 T's clarification about the direction of the tilted axis)	17:30 - - 4 12
18	02:00 -45:00 WCD, T's explanation (mostly T's talk)	43
19 *	05:30 – 36:26 WCD (CRS Q) *	31

BIBLIOGRAPHY

Ainsworth, S., & Loizou, A. T. (2003). The effects of self-explaining when learning with text or diagrams. *Cognitive Science*, 27(4), 669-681.

Arnheim, R. (1969). *Visual thinking*. Berkeley, CA: University of California Press.

Atwood, R. K., & Atwood, V. A. (1996). Preservice elementary teachers' conceptions of the cause of seasons. *Journal of Research in Science Teaching*, 33(5), 553-563.

Badders, W., Bethel, L., Fu, V., Peck, D., Sumners, C., Valentino, C., & Mullane, R. (1996). *Science Discovery Works: The Solar System and Beyond*. Parsippany, NJ: Silver Burdett Ginn.

Bakhtin, M. M. (1984). Problem of Dostoevsky's poetics. Minneapolis, MN: University of Minnesota Press.

Baxter, J. (1991). A constructivist approach to astronomy in the national curriculum. *Physics Education*, 26, 38-45.

Baxter, J. (1989). Children's understanding of familiar astronomical events. *International Journal of Science Education*. 11, 502-513.

Beatty, I. (2004). Transforming students learning with classroom communication systems. *Education Center for Applied Research*, 3, February.

Beatty, I. D., & Gerace, W. J. (2009). Technology-enhanced formative assessment: A research-based pedagogy for teaching science with classroom response technology. *Journal of Science Education and Technology*, 18(2), 146-162.

Beatty, I. D., Feldman, A., Leonard, W., Gerace, W., St. Cyr, K., Lee, H., & Harris, R. (2008). Teacher learning of technology-enhanced formative assessment. Paper was presented at the *Annual International Conference of the US National Association for Research in Science Teaching*, Baltimore, MD.

Berger, J. (1972). *Ways of seeing*. London: Penguin Books.

Berk, L & Winsler, A. (1995). "Vygotsky: His life and works" and "Vygotsky's approach to development". In *Scaffolding children's learning: Vygotsky and early childhood learning*, National Association for Education Of Young Children.

Black, P., & William, D. (2005). Developing a theory of formative assessment. In: Gardneer J. (ed.) Assessment and Learning. Sage Books, London, pp.81-100.

Black, P., & William, D. (1998). Inside the black box: raising standards through classroom assessment. *Phi Delta Kappan*, 80(2), 139-148.

Bowen, G. M., & Roth, W.-M. (2005). Data and graph interpretation practices amongst pre-service science teachers. *Journal of Research in Science Teaching*, 42(10), 1063-1088.

Bruffee , K. A. (1993). *Collaborative Learning: Higher Education, Interdependece, and the Authority of Knowledge.* John Hopkins, Baltimore.

Buckley, B. C. (2000). Interactive multimedia and model-based learning in biology. International Journal of Science Education, 22(9), 895-935.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, 8, 293-332.

Chin, C. (2007). Teacher questioning in science classrooms: approaches that stimulate productive thinking. *Journal of Research in Science Teaching*, 44(6), 815-843.

Chin, C. (2006). Classroom interaction in science: Teacher questioning and feedback to students' responses. *International Journal of Science Education*, 28(11), 1315-1346.

Clement, J. (1993). Using Bridging Analogies and Anchoring Intuitions to Deal with Students' Preconceptions in Physics. *Journal of Research in Science Teaching*, 30(10), 1241-1257.

Clement, J. (1989). Learning via model construction and criticism. In C. Reynolds (Ed.), *Handbook of creativity Assessment, theory and research* (pp. 341-381). New York: Plenum.

Cobb, P., & Yackel, E. (1996). Constructivist, emergent, and sociocultural perspectives in the context of developmental research. *Educational Psychologist*, 31(3/4), 175-190.

Comins, N. F. (2001). *Heavenly Errors: Misconceptions about the real nature of the universe*. Columbia University Press, NY.

Cook, M. P. (2006). Visual Representations in Science Education: The Influences of Prior Knowledge and Cognitive Load Theory on Instructional Design Principles. *Science education*. Wiley Periodicals, Inc., 1073-1091.

Corbin, J., & Strauss, A. (2008). *Basics of Qualitative Research*. Third edition. Sage Publications, Inc. CA.

Cowie, B., & Bell, B. (1999). A model of formative assessment in science education. *Assessment in Education*, 6(1), 101-116.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, 10 (2 & 3), 105-225.

Doolittle, P. E. (1999). *Constructivism and online education*. Virginia Polytechnic Institute and State University.

Driver, R., & Bell, B. (1986). Students' thinking and the learning of science: a constructivist view. *School Science Review*. 67(240). 443-456.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education*, 5, 61-84.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, 84 (3), 287-312.

Dufresne, R. J., Gerace, W. J., Leonard, W. J., Mestre, J. P., & Wenk, L. (1996). Classtalk: A classroom communication system for active learning. *Journal of Computing in Higher Education*, 7, 3-47.

Dunlop, J. (2000). How children observe the universe. Publication of Astronomical Society of Australia. 17, 194-206.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: developments in the application of Toulmin's Argument Pattern for studying science discourse. *Science Education*, 88 (6), 915-933.

Feldman, A., & Capobianco, B. (2003). Real-time formative assessment: A study of teachers' use of an electronic response system to facilitate serious discussion about physics concepts. Presented at 2003 Annual meeting of the American Educational Research Association. Chicago, Illinois.

Feuerstein, R., Rand, Y., Hoffman, M. B., & Miller, R. (1980). *Instrumental Enrichment: An Intervention Program for Cognitive Modifiability*. University Park, Baltimore.

Gagné, R. M. (1985). *The conditions of learning and theory of instruction.* 4th edition. New York: Holt, Rinehart, and Winston.

Gagné, R. M., & Glaser, R. (1987). *Foundations in Learning Research*. In Gagné, R. M (Ed.), Instructional Technology: Foundations (pp. 49-82). Lawrence Erlbaum Associates.

Gokhale, A. A. (1995). Collaborative learning enhances critical thinking. Journal of Technology Education, 7(1), 22-30.

Gravetter, F. J., & Wallnau, L. B. (2000). Statistics for the Behavioral Sciences: a first course for students of psychology and education (5th ed.). Wadsworth Inc. CA.

Hegarty, M. (2004). Dynamic visualizations and learning: getting to the difficult questions. *Learning and Instruction*, 14, 343-351.

Hogan, K., Nastasi, B. K., & Pressley, M. (2000). Discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. *Cognition and Instruction*, 17(4), 379-432.

Housen, A. C. (2001-2002). Aesthetic thought, critical thinking and transfer. *Arts and Learning Research Journal*, 18 (1), 99 - 131.

Johnson, R. T., & Johnson, D. W. (1986). Action research: Cooperative learning in the science classroom. *Science and Children*, 24, 31-32.

Jonassen, D., Mayes, T., & McAleese, R. (1993). *A manifesto for a constructivist approach to uses of technology in higher education.* In T.M. Duffy, J. Lowyck, & D.H. Jonassen (Ed.), Designing Environments for Constructive Learning. Springer-Verlag, Berlin.

Jones, B., Lynch, P., & Reesink, C. (1987). Children's conceptions of the Earth, Sun and Moon. *International Journal of Science Education*, 9(1), 43-53.

Kirschner, P. A. (2002). Cognitive load theory: Implications of cognitive load theory on the design of learning. *Learning and Instruction*, 12(1), 1-10.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education*, 77 (3), 319-337.

Lee, H., Feldman, A., & Beatty, I. D. (2011). Factors that affect science and mathematics teachers' initial implementation of Technology-Enhanced Formative Assessment using a classroom response system. *Journal of Science Education and Technology*. doi: 10.1007/s10956-011-9344-x

Lee, H., Feldman, A., & Beatty, I. D. (2009). Teachers' implementation of classroom response system to perform formative assessment in secondary science/math classes. Proceeding paper presented at annual meeting of National Association of Research in Science Teaching: Garden Grove, CA.

Lewalter, D. (2003). Cognitive strategies for learning from static and dynamic visuals. *Learning and Instruction*, 13, 177-189.

Livingston, E. (1995). *An anthropology of reading*. Bloomington, In: Indiana University Press.

Lobel, M., Neubauer, M., & Swedburg, R. (2005). Comparing how students collaborate to learn about the self and relationships in a real-time non-turn-taking online and turn-taking face-to-face environment. *Journal of computer-mediated communication,* 10(4), article 18.

Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. Learning and Instruction, 13(2), 157-176.

Lowe, R. K. (1999). Extracting information from an animation during complex visual learning. European Journal of Psychology of Education, 14, 225-244.

Mathewson, J. H. (1999). Visual-spatial thinking: An aspect of science overlooked by educators. *Science Education*, 83(1), 33-54.

Mayer, R. E. (2001). *Multimedia learning*. New York: Cambridge University Press.

Mayer, R. E. (1999a). Multimedia aids to problem-solving transfer. *International Journal of Educational Research*, *31*, 611–623.

Mayer, R. E. (1999b). Research-based principles for the design of instructional messages. *Document Design*, *1*, 7–20.

Mayer, R. E. (1997). Multimedia learning: are we asking the right question? *Educational Psychologist*, 32(1), 1-19.

Mayer, R. E., Bove, W., Bryman, A., Mars, R., & Tapangco, L. (1996). When less is more: Meaningful learning from visual and verbal summaries of science textbook lessons. *Journal of Educational Psychology*, 88(1), 64-73.

Mayer, R. E., Heiser, J., & Lonn, S. (2001). Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology*, 93(1), 187-198.

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, 38(1), 43-52.

Mayer, R. E., & Moreno, R. (2002a). Aids to computer-based multimedia learning. *Learning and Instruction*, 12(1), 107-119.

Mayer, R. E. & Moreno, R. (2002b). Animation as aid to multimedia learning. *Educational Psychology Review,* 14(1), 87-99.

Mehan, H. (1979). Learning lessons. Cambridge, MA: Harvard University Press.

Miles, M. B., & Huberman, A. M. (1994). Qualitative Data Analysis. The second edition. Sage Publications Inc. CA.

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. Journal of Educational Psychology. 91(2), 358-368.

Mortimer, E. F., & Scott, P. H. (2003). Meaning making in secondary science classrooms. Maidenhead, UK: Open University Press.

Myers, G. (1988). Every picture tells a story: Illustrations in E.O. Wilson's sociobiology, *Human Studies*, 11, 235-269.

National Research Council (1996). National Science Education Standards: Washington, DC, National Academy of Sciences Press, 262 p.

Neisser, U. (1997). Rising scores on intelligence tests. *American Scientist*, 85, 440-447.

Newberry, M. (2002). *Pupils' understanding of diagrams in science: Progression from key stage 3 (11-14 years) and across key stage 4 (14-16 years)*. Fareham, Hants: Cams Hill School.

Newport (2004). *The effect of classroom performance systems in a science classroom*. Master's thesis. Emporia State University.

Nussbaum, J. & Novak, J. D. (1976). An assessment of children's concepts of the earth utilizing structured interviews. *Science Education*, 60(4), 535-550.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent Developments. Educational Psychologist, 38(1), 1-4.

Paivio, A. (1986). *Mental Representations: A Dual Coding Approach*, Oxford University Press, Oxford, England.

Park, O.-C., & Hopkins, R. (1993). Instructional conditions for using dynamic visual displays: a review. *Instructional Science*, 21, 427-449.

Peeck, J. (1993). Increasing picture effects in learning from illustrated text. *Learning and Instruction,* 3, 227-238.

Perner, J. (1991). Understanding the representational mind. The MIT Press, Cambridge, MA.

Piaget, J. (1950). *The Psychology of Intelligence*. New York: Routledge

Pozzer-Ardenghi, L., & Roth, W.-M. (2005). Photographs in lectures: Gestures as meaning-making resources. *Linguistics and Education*, 15, 275-293.

Pozzer-Ardenghi, L., & Roth, W.-M. (2004). Making sense of photographs. *Science Education*, 89(2), 219-241.

Pozzer, L. L., & Roth, W.-M. (2003). Prevalence, function, and structure of photographs in high school biology textbooks. *Journal of Research in Science Teaching*, 40, 1089-1114.

Rea-Ramirez, M. A., Nunez-Oviedo, M. C., & Clement, J. (2009). Role of discrepant questioning leading to model element modification. Journal of Science Teacher Education, 20 (2), 95-111.

Rogers, R. (2003). Using personal response system to engage students and enhance learning. Presented at the Making Statistics More effective in Schools and Business conference, Georgetown University, Washington, DC.

Roth, W.-M. (2003a). Gesture-speech phenomena, learn-ing and development. *Educational Psychologist*, 38 (4), 249-263.

Roth, W.-M. (2003b). From epistemic (ergotic) actions to scientific discourse: Do gestures obtain a bridging function? *Pragmatics & Cognition*, 11, 139-168.

Roth, W.-M. (1996). Teacher questioning in an open-inquiry learning environment: Interactions of context, content, and student responses. *Journal of Research in Science Teaching*, 33(7), 709-736.

Roth, W.-M., & Lawless, D. (2002). Scientific investigations, metaphorical gestures, and the emergence of abstract scientific concepts. *Learning and Instruction*, 12, 285-304.

Roth, W.-M., & McGinn, M. K. (1998). Inscriptions: Toward a theory of representing as social practice. *Review of Educational Research*, 68(1), 35-59.

Roth, W.-M., Bowen, G. M., & McGinn, M. K. (1999). Differences in graph-related practices between high school biology textbooks and scientific ecology journals. *Journal of Research in Science Teaching*, 36(9), 977-1019.

Sadler, P., (1992). The initial knowledge state of high school astronomy students. Ed.D. Dissertation, Harvard School of Education.

Sadler, R. (1989). Formative assessment and the design of instructional systems. *Instructional Science*, 18(2), 119-144.

Schneps, M. H., Sadler, P. M., Woll, S., & Crouse, L. (1989). *A Private Universe*. Film produced by the Harvard-Smithsonian Center for Astrophysics.

Schur, Y. & Galili, I. Multiple perspectives of physics learners using Thinking Journey in a computerized model, not published article.

Schur, Y., Skuy, M., Zietsman, A., & Fridjhon, P. (2002). A thinking journey based on constructivism and mediated learning experience as a vehicle for teaching science to low functioning students and enhancing their cognitive skills. *School Psychology International*, 23(1), 36-67.

Schur, Y., Pensso, H., & Schwarz, B. (2007). Chapter 9: Description of the experimentations in Israel. ESCALATE: The White Book. pp.263-292.

Shapiro, T. (2007). Evaluating the thinking journey mode of teaching as applied in learning the concept of day/night cycle. Master thesis at the Hebrew University of Jerusalem.

Strauss, A., & Corbin, J. (1990). *Basics of Qualitative Research: grounded theory procedures and techniques*. Sage Publications, Inc. CA.

Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, 10, 251-296.

Taylor, I. J. (1996). Illuminating lunar phases. *The Science Teacher*, 63, 39-41.

Toulmin, S. (1958). The Uses of Argument. Cambridge University Press: England.

Trees, A., & Jackson, M. (2003). The learning environment in clicker classrooms: Students processesof learning and involvement in large courses using student response systems. Communications Department, University of Colorado.

Tsai, C.-C., & Chang, C.-Y. (2005). Lasting effects of instruction guided by the conflict map: Experimental study of learning about the causes of the seasons. Journal of Research in Science Teaching, 42(10), 1089-1111.

Tufte, E. R. (1983). *The visual display of quantitative information*. Cheshire, Connecticut: Graphics Press.

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

van Zee, E., & Minstrell, J. (1997b). Reflective discourse: developing shared understandings in a physics classroom. International Journal of Science Education, 19 (2), 209-228.

van Zee, E., Iwasyk, M., Kurose, A., Simpson, D., & Wild, J. (2001). Student and teacher questioning during conversations about science. *Journal of Research in Science Teaching,* 38(2), 159-190.

von Glasersfeld, E. (1995). *A constructivist approach to teaching.* In L. P. Steffe & J. Gale, Constructivism in education. Hillsdale, NJ: Erlbarum.

von Glasersfeld, E. (1984). *An introduction to radical constructivism*. In P. Watzlawick (Ed.), The invented reality. New York: Norton.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, 4, 45-69.

Vosniadou, S., & Brewer, W. F. (1994). Mental models of the day/night cycle. *Cognitive Science*, 18(1), 123-184.

Vygotsky, L.S. (1978). *Mind and society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wang, C., & Burris, M.A. (1997). Photovoice: concept, methodology, and use for participatory needs assessment. *Health Education and Behavior*, 24(3), 369-387.

Webb, N. M. (1982). Student interaction and learning in small groups. *Review of Educational Research*, 52 (3), 421-445.