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Photographs and Classroom Response Systems in Middle School Astronomy Classes

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Abstract In spite of being readily available, photographs have played a minor and passive role in science classes. In our study, we present an active way of using photographs in classroom discussions with the use of a classroom response system (CRS) in middle school astronomy classes to teach the concepts of day–night and seasonal change. In this new pedagogical method, students *observe* objects or phenomena in photographs and use the information to develop understanding of the scientific concepts. They share their ideas in classroom discussion with the assistance of the CRS. Pre- and posttest results showed that the new pedagogy helped students overcome primitive conceptions and enhanced their understanding of the concepts. The observation of the rich details of photographs played three pedagogical roles in classroom discussion: easing students' anxiety about learning a new scientific concept; continuous stimulus of learning; and as evidence or data.

Keywords Photographs · Classroom response systems · Day–night and seasonal change · Earth science education · K-12

Introduction

It has been reported that students have various misconceptions about *day–night* and *seasonal change* and that they are difficult concepts to teach (Plummer 2009; Sadler 1987, 1992; Vosniadou 1994; Zeilik and Morris 2003). Ironically, those concepts are closely related to our daily lives. We experience day and night every day, and most parts of the earth experience different seasons throughout the year. They are fundamental concepts in K-12 science curricula (National Research Council 1996; NGSS Lead States 2013). They should be familiar concepts, then, why do so many students have difficulty in understanding them?

One of the reasons may be found from the failure to connect the concepts with what students observe in a real world (e.g., Vosniadou and Brewer 1994). Students may have been more focused on learning the scientific *fact*s than developing deep insights about how scientific knowledge could relate to what they experience in daily lives. Therefore, their knowledge often may be superficial, which prevents them from being able to see the connection between what they observe on earth and what they learn in science classes.

A basic tenet of the nature of science is that it is empirical (Lederman 2007). Therefore, observation is the initial basis for scientific research. Scientists gather information from their observations and investigate why such things happen. The data are collected in various forms, and photographs may be one of the most fundamental and widely used ones. For example, biologists take the photographs of cell microstructures to investigate the mechanisms of cells. Geologists use the photographs of Mars to uncover its composition and physical processes. Astronomers use the photographs of galaxies taken in several wavelengths light to find out the dynamics and formation of galaxies. Photographs are one of the types of data that scientists actually *use* for their scientific research.

Photographs may be used in different ways in science. They are data that scientists use for scientific research, which is an empirical approach. Scientists observe concrete phenomena or objects via photographs, gather the

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information from them, analyze the information, and draw a conclusion about the abstract scientific concept. Photographs are also used to describe a scientific result, or to show phenomena or objects to other scientists, students, or the public, which is a didactic approach. And lastly, photographs are used as art to attract students and the public to the beauty of science. While the *bottom-up* approach is valued in professional science, the *top-down* or *esthetic* function is more common in traditional science classes.

There is a tremendous amount of photographs available that are applicable to science classes (e.g., Brown et al. 1995), but their use has been limited and conservative (Gilbert 2008). In this study, we report on the use of a bottom-up approach to promote student learning through classroom discussion about photographs with the assistance of a classroom response system (CRS). Below, we review the theoretical framework of our study.

Theoretical Framework

Misinterpretation About the Observation of the World

Students come to science class with already formed ideas from their experiences (Driver and Bell 1986). Their preconceptions are often recognized as misconceptions that are not accepted by current science, including those about day–night or seasonal change, which have been well reported in previous studies (Agan 2004; Atwood and Atwood 1996; Baxter 1989; Dunlop 2000; Kikas 2004; Sadler 1987, 1992; Trumper 2001; Vosniadou and Brewer 1994; Zeilik and Morris 2003). Some misconceptions are persistent even after extensive instruction. For example, Sadler (1987) reported that students who had a one-year earth science course did not show much difference in providing correct answers about the cause of the seasons or the phases of the moon than students who did not take it. He also reported that students who learned the reason for the seasonal change still held the misconception about distance although they recognized the earth's tilt as an important factor for the seasons (Sadler 1992).

Vosniadou and Brewer (1994) argued that many of the misconceptions were created from students' everyday observations, which they interpreted using presuppositions from their cultural context. The authors explained that epistemological presuppositions (e.g., phenomena need to be explained) and ontological presuppositions (e.g., physical objects are solid and stable) combine with students' observations about day–night in their daily lives (e.g., the sun is in the sky in daytime, but not in nighttime; the moon is in the sky in nighttime, but not in daytime), which creates a belief that the appearance of the sun and the disappearance of the moon cause day, and vice versa for causing night. In other words, how students interpret their observations of natural phenomena affects the development of their scientific conceptions.

Photographs in Science Education

Photographs represent the lived world in the form of visual representations that can be shared with others. Myers (1988) described that photographs "present the background as a space continuous with our own … Photographs come with apparent self-evidence, because they are taken as mechanical reproductions of an image" (p. 239). Pozzer-Ardenghi and Roth (2005) also noted "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" (p. 277). While photographs represent the lived world and can give opportunities of observing natural phenomena as professional scientists do, the use of photographs in science classes has been limited and conservative. In addition, there are very few studies about photographs in science education (Gilbert 2008). For example, Pozzer and Roth distinguished functions of photographs in relation to captions and texts in high school biology textbooks (Pozzer and Roth 2003, 2004), and they identified types of teacher gestures presented when lecturing with photographs (Pozzer-Ardenghi and Roth 2005).

Some researchers have been looking at ways that photographs could be used for various instructional purposes (Eshach 2010; Katz 2011). For example, Eshach (2010) asked pre-service teachers to create and interpret photographs to investigate their misconceptions about the concept of Newton's third law. Yaron Schur and his colleagues in their project, *Thinking Journey* (TJ), (Schur and Galili 2009; Yair et al. 2003) presented students with various visual materials and questions in the context of imaginary journeys. For example, one TJ unit provides students with a series of photographs of the moon and the earth and asks them to imagine that they are traveling to the moon, observing day–night phenomenon on the moon, and returning to the earth and observing it again (Shapiro 2007). Through the successive activities, students recognize the variation of perspectives and their relationship with various environments. A major aspect of the theoretical framework of our study is TJ's use of photographs in classroom discussion. While TJ emphasizes imaginary journeys for students to feel like traveling by the use of successive visual materials, our study focuses on using photographs as a way of giving students opportunities to observe natural phenomena and to find answers for questions with the assist of CRSs by sharing their thoughts in classroom discussion using the pedagogy of *Technology-Enhanced Formative Assessment* (*TEFA*).

Technology-Enhanced Formative Assessment Pedagogy

TEFA pedagogy is based on four principles (Beatty and Gerace 2009): *question-driven instruction*—the use of conceptual questions that are often challenging and motivate students to learn; *dialogical discourse*—the promotion of students–teacher interactions in classroom discussion; *formative assessment*—teachers use of feedback from students to revise their teaching practice in a timely manner; and *meta-level communication*—teachers discussion with their students the goals and processes of learning. TEFA pedagogy implements these principles using CRSs in a series of activities called a *question cycle* (Dufresne et al. 1996): teachers present multiple-choice or simple questions to the class, students work on the question with peers or individually, they send their answers to the system using individual clickers, the system shows a histogram integrating their responses, and teachers facilitate classroom discussion based on the histogram result and then clarify the concept with closure.

CRSs are an educational technology that instantly gathers students' responses to simple or multiple-choice questions and shows the aggregated results on histograms that instructors as well as students can see in class. CRSs are also called *voting systems, audience response systems, classroom communication systems*, or simply *clickers*. The uses of CRSs vary from attendance checking to student testing, but recent studies focus more on its educative value of assisting classroom discussion (Feldman and Capobianco 2008; Kay and Knaack 2009). Indeed, there is good agreement in previous studies that the use of CRSs promotes classroom discussion, encourages students' engagement, and increases students' interest in learning (Bullock et al. 2002; Dufresne et al. 1996; Fies and Marshall, 2006).

During the last decade, studies about the use of CRSs have focused mainly on pedagogical theories or their simple implementation in classes (Fies and Marshall 2006). These studies have contributed to the development of pedagogical principles for students' learning with CRSs and to uncover students' attitudes about CRS itself. However, there is still uncertainty about what the use of CRSs adds to the teaching and learning of science, as Fies and Marshall noted, "It is time to move beyond anecdotes and beyond traditional classroom pedagogies. It is time to define what it is that a CRS can add to a learning environment" (2006, p. 106).

In this study, we investigate students' learning experience when CRSs are combined with visual stimuli in middle school astronomy classes. In this new pedagogy, which we call Photo TEFA (P+TEFA), students observe and discuss their observations of natural phenomena in lessons facilitated by the use of a CRS. By investigating participating students' and teacher's perceptions, we seek to understand the pedagogical roles of photographs in a discussion-oriented pedagogy.

Methods

Curriculum Development

We developed a new curriculum unit for sixth-grade science classes that focused on the topics of day–night and seasonal change. The unit consisted primarily of photographs and relevant and appropriate conceptual CRS questions. The questions were designed to help students develop their reasoning through inquiry, rather than to simply measure whether or not they gave a correct answer. Photographs were either in the public domain that we found from Internet Web sites or were taken by the first author. Activity sheets were also developed to accompany the lessons. The curriculum unit included small group hands-on activities and presentation. Examples of the usage of photographs and CRS questions in class are described later in this paper.

Setting and Participants

The unit was implemented in a middle school located in a small city in the northeast USA. The participants were Mary, a middle school science teacher, and her sixth-grade students. Mary had taught astronomy at the middle school for more than 10 years. In summer 2008, she participated in a 3-day summer workshop in which she learned the principles of the TEFA pedagogy and how to use a CRS in her classroom. During that summer, we developed the curriculum unit and discussed it with her. In fall 2008, she taught five sections of sixth-grade astronomy and each class size was 18–20 students. Two of the classes were taught with the lessons that we designed (intervention group). The other three classes were taught as the same way that Mary had taught in previous years (traditional group).

We want to note that we do not think of the traditional group as being the equivalent of a control group in an experimental study. Due to the unexpectedly slow pace of discussion, the intervention group took more class time than the traditional group to cover the topics. Instead, the traditional group is used as a reference to learn more about what happened in the intervention group. Therefore, we prefer using the words intervention/traditional rather than experimental/control.

Data Collection

All class sessions during which the unit was implemented were observed, and field notes were taken. In addition, all of these classes were video-recorded. We administered tests of students' conceptions of day/night and the cause of the seasons before (pretest) and after the instruction (posttest) in both intervention and traditional groups. The same questions were used for both pre- and posttests, and they were all open-ended. Students completed the tests individually in the class without looking at textbooks or any materials. We also administered an attitude survey asking about students' experiences learning with the photographs and the CRS in the intervention classes after they completed the unit. Additionally, the students were asked to write their thoughts about "today's lesson" at the end of each class (daily response).

We interviewed the teacher six times during the study: once before the curriculum unit began (pre-interview); four times during the unit (mid-interviews); and once again after all the lessons were taught (post-interview). Most interview questions were prepared beforehand, and additional questions were asked when necessary during the interviews for clarification. In addition to research purposes, we also used the interviews formatively. Based on the interviews, we sometimes revised the lessons if Mary did not feel comfortable to teach the content or if there was anything that she thought that needed to be modified. All the interviews were audio-recorded and transcribed verbatim.

Analysis

The video recordings of the classes were transcribed verbatim and used to identify various teaching modes and to measure their time span. This provided us with a measure of how the teacher used her class time in the traditional group and in the intervention group.

Students' pre- and post-conception tests were analyzed using rubrics. This was a blind-review process in which the students' class numbers and IDs were covered. Pretest scores and posttest scores were compared to measure each student's knowledge gain. Reliability of the analysis with the rubrics was tested in two ways. The first way was through repeated scoring done by the first author. This was to build more sophisticated standards for the rubrics and to train the author herself to uniformly measure student performances. When there were vague responses to measure, they were categorized into groups and more detailed standards were added to the rubrics with sub-categories. Students' performances on the test were measured again with the revised rubrics. This was repeated several times until the rubrics were clear enough to accurately measure student performances and the scores agreed with previous measures. The second way that reliability was increased was by enlisting a doctoral candidate in astronomy to score the tests using the rubrics. After being acquainted with the rubrics, he randomly chose 12 students' responses and scored them. Among 72 questions, the scores of only two questions were slightly different in the range of sub-categories from what we had scored. Given that, we consider the measure of students' performances to be reliable.

The attitude survey consisted of open-ended and Likert-type questions. The Likert-type questions asked about students' learning experiences in the new lessons. The possible responses were Strongly No, No, I don't know, Yes, and Strongly Yes. The number of students for each choice was counted for each item.

The open-ended responses of the attitude survey, daily responses, and teacher interview transcriptions were analyzed following the grounded-theory approach by firstly conceptualizing their responses with open coding, categorizing the codes into similar concepts, and finding out common themes across individuals (Corbin and Strauss 2007). These data allowed us to uncover the teacher's and the students' perceptions about the new pedagogy. The video recordings of the classes, students' attitude survey and daily responses, and teacher interview data were triangulated to identify the pedagogical roles of photographs in the lessons.

Findings

This section begins by introducing the classroom dynamics of the intervention classes. We then present the findings from the students' pre- and post-conception tests, teacher interviews, and the students' attitude survey and daily responses. Individual students are represented by *S* followed by their student number. In the quotes, *Int* means the intervention class, *pre* is for pretest, and *post* is for posttest. *Att #* is the question number of the attitude survey, and responses to the daily questions are presented with the date that the students responded. Quotes from the teacher interviews are provided with the date of the interview in parentheses.

Classroom Dynamics

The intervention classes started with the teacher projecting a photograph on to a screen located in the front of the classroom. For example, Mary and her students started conversation as she presented the photograph A of Q1 in Table 1.

T What can you tell us about the photo, S5?
S5 The sun's going down
T Ok, why do you say that the sun's going down?
S5 Because the sun is like higher in the sky and you can see the lights on the trees
T Ok, anything else? S11?

Table 1 Examples of CRS questions

Photographs		CRS questions	Note
Photograph A 	Photograph B 	Q1. Both photographs were taken at same place on same day. Imagine that you were in the place when the photographs were taken. In which one would you feel hotter? (a) when photograph A was taken (b) when photograph B was taken (c) same at A & B (d) None of the above	The angle of the sun and its temperature on the earth surface
		Q2. This photograph was taken near the north pole in December. When do you think it was? (a) At noon (b) At midnight (c) At dawn or sunset	Polar darkness. Different length of daytime at different places on earth

S11 I see the sun rising because usually when it's setting the sun is more orange

When presenting a photograph, it was natural for Mary to ask the students, "What do you see in the photograph?" The students immediately responded enthusiastically about their observations of the photograph. After sharing their observations for a while, Mary presented a CRS question. The students worked on the question with peers or individually. Sometimes small group discussions with hands-on activities were performed in this phase. When they decided on their answers, they individually sent their responses using their own CRS *clickers*. The system displayed the result as a histogram on the screen, and Mary started facilitating the classroom discussion by asking why some students had chosen certain answers, such as "Why do you think so many people chose (b)?" Most students actively participated in discussion by sharing their ideas. They also often referred to their experiences, for example, S38: "because *usually* at sunset, the clouds are usually pink or orange." Mary often went back to the histogram and asked for different answer choices. She tried not to cut off student reasoning and tried hard to hear various student voices and encouraged them to speak out their opinions.

As the discussion went on, the students were able to develop higher-order thinking and their understanding became closer to the target scientific concept. For example, in one lesson, there was a classroom discussion about the phenomena polar darkness and white night, which happens in the polar regions during the winter and summer months. Mary started the discussion by presenting the photograph of Q2 in Table 1. After the students shared what they saw in the photograph, Mary presented the CRS question. Most students thought that the photograph had been taken at dawn or sunset because the sun is on the horizon. But they were surprised to know that just right above the horizon was the highest position of the sun in the sky observed in the Pole area in wintertime. In the CRS question, the photograph showed the students a *discrepant event* (Thompson 1989) that they had not expected. Then, Mary asked the students why this phenomenon could happen on earth. The students started to reason from their experience, for example, S28: "Ahm, in the winter, sunrise and sunset would have been different, because it means when the sun comes out at different time at different day"; and S22: "since like the colder the climates usually days are shorter and nights are longer, so they were thinking that one part of the earth, in this picture it is Antarctica, this could be (a)." The conversation continued:

S35 I chose (a) because in different regions if you are in north pole, I think like what S22 said, here in Massachusetts it could be sleeping at the time but when here in north pole or south pole usually in the middle of the day gets really dark because of what time a day it revolves around the sun, so I chose (a)

T Ok, can you say a little bit more about why, you just said about earth rotation?

S35 Around the sun. When the earth rotates around the sun, *sun is pointing out one side of the earth,* and if you are at North Pole, the sun would be on the certain side, like if you are at here, it would be different time in Massachusetts than that it is North Pole

T Ok, could it be noon in Massachusetts and noon some place at the North Pole at the same time?

S27 It depends on where it is

T But look like this [pointing at the photo on screen] at the North Pole? It never looks like that at noon on the North Pole? S34, what do you think?

S34 Almost like what S35 said but in *North Pole maybe at noon, it might get darker* since it's more colder there? And, Massachusetts *where we are a lot lighter at this time*?

T Ok. S24?

S24 At noon, near, I mean it might look like that because *the sun is facing on* where we are, here it's up there, *so sun might not directly shine on that*, so it could be on the side

T Sun may not hit all of the North Pole? [S24: yeah] S27?

S27 Yeah, I think it's like the sun *more direct* nearly equator so it's always hot there, the farther you go up it gets colder than Mass*, so it's like north pole has less hours of daylight because less sun could have*

Looking at the photograph, S35 imagined the bird-eye view of the earth rotating around the sun and mentioned *"sun is pointing out one side of the earth."* Then, S34 brought up a conception that certain places could be darker than other places at the same time, saying, "… *North Pole maybe at noon it might get darker* …and, … *where we are a lot lighter at this time."* After then, S24 got the idea of the tilt of the surface and the angle of the sunlight, saying, "because *the sun is facing on* where we are, here it's up there, *so sun might not directly shine on that*…" This idea was developed to be more scientifically accurate, as can be seen in S27's quote, "it's like the sun *more direct* nearly equator so it's always hot there, the farther you go up it gets colder than Mass*, so it's like north pole has less hours of daylight because less sun could have."* S27 was reasoning using the scientific concepts that the equator has more direct sunlight, and the poles have less hours of daytime. The students observed the photograph, brought up their daily experiences and prior knowledge, developed their reasoning by sharing their ideas, and their understanding about the phenomena became closer to the abstract scientific concept. Usually after having such classroom discussions, Mary wrapped up the discussion at the end with clarification of any confusion. This cycle was resumed with a new photograph and a new question.

Figure 1 shows the percentage of average class time that the three traditional classes and the two intervention classes spent during the study. The traditional group spent most of the class time on direct teacher instruction and students' individual work of reading the textbook or doing worksheets. This is an indication that Mary's teaching in the past had generally been teacher-centered and relied on reading materials and worksheets. On the other hand, the intervention group spent most of their time on whole classroom discussion. With the new pedagogy, Mary minimized her frontal teaching and focused more on student-centered classroom discussion. In Fig. 1, preparation is the non-instructional time such as when the students first walked into the classroom, changed seats for activities, or when Mary was settling them down. The intervention group spent double the time on preparation due to the manipulation of computers and software for using the CRSs.

Student Achievement

It should be clear from the previous section that the students in the intervention classes had a very different learning experience than those in the traditional classes. How then, are the students' learning different between the groups? While we cannot directly compare the students' knowledge gain between the traditional and the intervention groups due to the different amounts of class time taken to cover the topics, it is still meaningful to examine students' performances on the pre- and posttests.

We evaluated the students' responses to the open-ended questions in the pre- and posttests using rubrics. The rubrics were divided into four levels: *primitive response*, *non-scientific explanation*, *partially correct but not complete scientific explanation,* and *scientifically correct explanation*. Both *primitive responses* and *non-scientific explanations* are not scientifically correct. *Primitive responses* are the crudest status of knowledge that is learned from experiences. For example, quite a large number of students had *primitive* ideas that day–night happens because it is necessary for our daily lives, "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). Similarly, many students believed that seasonal change was caused by weather or climate. Their ideas were mostly constrained to the description about the direct observation of their daily experiences. On the other hand, *non-scientific explanations* are still naïve but include somewhat more advanced ideas than simple description, showing logical, but clumsy, reasoning. For example, students thought that the sun or the moon causes day–night phenomena on earth, or that the different distance between the earth and the sun causes seasonal change. *Partially correct but not complete scientific explanations* are when students give scientifically correct, but not full, information. For example, students may simply mention the earth's spin or tilted axis without further explanation about how it affects day–night or seasonal change. *Scientifically correct explanations* are those in which the response is an accurate and full scientific explanation.

Table 2 shows the number and percentage of students for each rubric category. In general, both groups improved

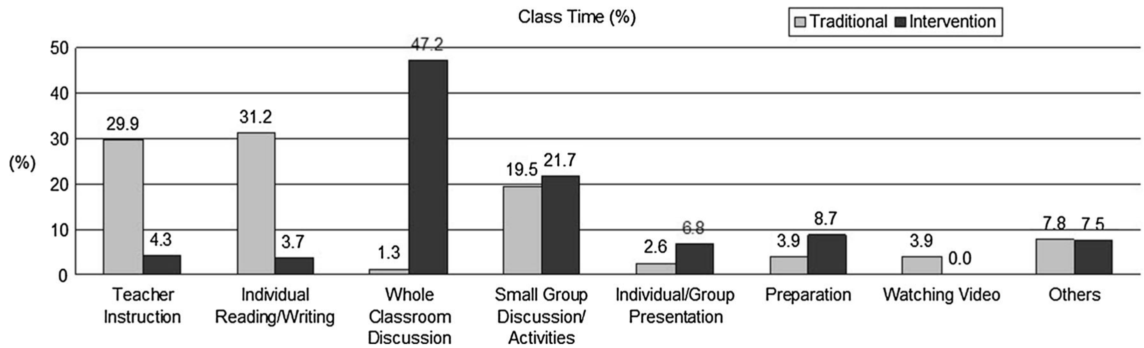

Fig. 1 Percentage of class time

Table 2 Number of students for each rubric category

Question /rubric categories	Intervention group (intervention classes 1 and 2)				Traditional group (traditional classes 1, 2, and 3)			
	Pre $n = 35$		Post $n = 36$		Pre $n = 58$		Post $n = 57$	
	#	(%)	#	(%)	#	(%)	#	(%)
Definition of Daytime								
Primitive response	8	(22.9)	3	(8.3)	6	(10.3)	6	(10.5)
Non-scientific	6	(17.1)	7	(19.4)	13	(22.4)	11	(19.3)
Partial understanding but not scientifically complete	15	(42.9)	11	(30.6)	27	(46.6)	24	(42.1)
Scientifically correct	6	(17.1)	15	(41.7)	12	(20.7)	16	(28.1)
Definition of nighttime								
Primitive response	7	(20.0)	4	(11.1)	9	(15.5)	8	(14.0)
Non-scientific	13	(37.1)	14	(38.9)	30	(51.7)	25	(43.9)
Partial understanding but not scientifically complete	8	(22.9)	5	(13.9)	12	(20.7)	10	(17.5)
Scientifically correct	7	(20.0)	13	(36.1)	7	(12.1)	14	(24.6)
Reason for day–night								
Primitive response	14	(40.0)	1	(2.8)	22	(37.9)	12	(21.1)
Non-scientific	5	(14.3)	3	(8.3)	6	(10.34)	5	(8.8)
Partial understanding but not scientifically complete	8	(22.9)	17	(47.2)	13	(22.41)	28	(49.1)
Scientifically correct	8	(22.9)	15	(41.7)	17	(29.31)	12	(21.1)
Reason for seasonal change on earth								
Primitive response	23	(65.7)	1	(2.9)	36	(65.5)	13	(22.8)
Non-scientific	9	(25.7)	6	(17.1)	15	(27.3)	12	(21.1)
Partial understanding but not scientifically complete	2	(5.7)	10	(28.6)	4	(7.3)	18	(31.6)
Scientifically correct	1	(2.9)	18	(51.4)	0	(0.0)	14	(24.6)
Diagram to explain the seasonal change on earth								
Primitive response	27	(77.1)	6	(17.1)	47	(85.5)	32	(60.4)
Non-scientific	6	(17.1)	6	(17.1)	7	(12.7)	6	(11.3)
Partial understanding but not scientifically complete	2	(5.7)	11	(31.4)	1	(1.8)	7	(13.2)
Scientifically correct	0	(0.0)	12	(34.3)	0	(0.0)	8	(15.1)

in the posttest, but there is a distinct difference in the category of *primitive response*. The percentage of primitive response for each question was similar for the groups in the pretest, but was different in the posttest. While only a small percentage of students presented primitive responses in the intervention group in the posttest, quite a high percentage of students still held primitive ideas in the traditional group in the posttest. This suggests that the new pedagogy of observing phenomena via photographs and sharing ideas in classroom discussion helped the students overcome their naïve conceptions. In addition, there was a much larger percentage increase in the number of scientifically correct responses in the intervention group than in the traditional group.

Students' and the Teacher's Perceptions About P+TEFA

Overall, the students' responses to the Likert-type questions in the attitude survey show that their perceptions about P+TEFA were generally positive (Table 3).

There was unanimous agreement among the students that they wanted their teacher to keep using the clickers (see A.2 in Table 3). Most students indicated that they thought that the photographs helped their content learning and helped them observe things around them and get more involved in class. They also enjoyed learning with the photographs and valued sharing their ideas in classroom discussion.

One of the attitude survey questions asked the students about the degree of difficulty of the lessons. Only three out of the 34 students thought that the lessons were *difficult* and none responded *very difficult*. Rather, most students thought that the lessons were *easy* (12), *very easy* (4), or chose *neutral* (15). Overall, they thought that the lessons learning with the photographs were easy and enjoyable. For example, the students mentioned, "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, Oct 7), "I felt that it was a great and easy way to learn" (S6, Att#4), and "I have felt like I knew everything you were talking about in class using photographs" (S23, Att#4).

The result that only a few of the students found the lessons to be difficult is interesting because in the baseline interview, Mary had been concerned about the level of difficulty of the lessons given the students' age. Once the lesson started, however, Mary was surprised by the level of the students' discussion, saying, "Just that how impressed I was by the 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 be able to do" (Nov 10), and "it's great to hear some students whose explanations [sounded like it] came out of a science book [when] it came from their own discussions and thoughts, and that's pretty amazing to me" (Nov 30). Mary was amazed by the students' explanations that were solely from their discussion although they did not use any textbook.

On the other hand, as this type of lesson was new to Mary, she encountered several difficulties in implementing the new pedagogy. Previous studies have reported that several factors can impede teachers from trying to implement TEFA pedagogy using CRSs (Lee et al. 2012). In this study, Mary was concerned about mainly three issues: facilitating classroom discussion; the slow pace of class and the need to cover content; and the students' ability to participate in lengthy whole classroom discussion. She was unsure about how long the discussion should go on and when to move to a next topic, and she was concerned about the level of each student's understanding. The classroom discussion often went slowly and took more time than expected. Mary thought that sixth-grade students might have not been prepared to participate in a lengthy whole classroom discussion, and so she wanted to spend plenty time on small group discussions in advance of large group discussions.

Although Mary experienced difficulties, she thought that the new lessons were beneficial to her teaching and her students' learning. Most of all, she valued her students' active participation in class, and the opportunities to hear various students' voices and to find the gap between her teaching and her students' understanding. For example, she said, "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" (Oct 30), "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" (Nov 10), and "some students really surprised me, … and these students that I didn't see participating before the study" (Nov 10).

Pedagogical Roles of Photographs in Classroom Discussion

The teacher interviews, students' attitude survey, and daily response data suggest several pedagogical roles of the CRSs that concur with what have been reported in previous studies (Bullock et al. 2002; Dufresne et al. 1996; Fies and Marshall 2006). For example, the students liked to use the CRSs because using them was *enjoyable and playful*. It amused the students and motivated their interests in class, noting, "I LOVE using the clickers so this to me was really, really fun. Go Clickers!! I want to use these things every day!!" (S11, Oct 9). The use of CRSs made the

Table 3 Students' perceptions about the use of CRSs and the photographs (total $n = 34$)

Category	Question	Number of students (percentage)		
		Disagree[†]	Neutral	Agree[†]
CRS: Interest	(A.1) It was a lot of fun to use clickers in class	0 (0.0 %)	1 (2.9 %)	33 (97.1 %)
	(A.2) I hope my teacher keeps using the clickers	0 (0.0 %)	0 (0.0 %)	34 (100.0 %)
	(A.3) The use of clickers made me more interested in learning astronomy	5 (14.7 %)	3 (8.8 %)	26 (76.5 %)
Photographs: Interest	(B.1) I really liked to see the photographs in class	0 (0.0 %)	6 (17.6 %)	28 (82.4 %)
	(B.2) I hope my teacher keeps using photographs in astronomy class	0 (0.0 %)	4 (11.8 %)	30 (88.2 %)
	(B.3) The photographs made me more interested in learning astronomy	6 (17.6 %)	5 (14.7 %)	23 (67.6 %)
Photographs: Content Learning	(C.1) The photographs made me think a lot about astronomy concepts	2 (5.9 %)	9 (26.5 %)	23 (67.6 %)
	(C.2) The photographs helped me to learn astronomy better	1 (2.9 %)	5 (14.7 %)	28 (82.4 %)
	(C.3) The photographs help me to learn different views about the concepts	0 (0.0 %)	6 (17.6 %)	28 (82.4 %)
Photographs: Observation	(D.1) The photographs helped me to notice scientific phenomena around me	2 (5.9 %)	8 (23.5 %)	24 (70.6 %)
	(D.2) The lessons with the photographs made me think more about things that happen around me	4 (11.8 %)	4 (11.8 %)	26 (76.5 %)
	(D.3) In general, my observation skill has been improved since completing this unit with the photographs	1 (2.9 %)	10 (29.4 %)	23 (67.6 %)
	(D.4) I found observing scientific events more often and in more detail since completing this unit with the photographs than before	1 (2.9 %	10 (29.4 %)	23 (67.6 %)
Photographs: Class Involvement	(E.1) Seeing photographs helped me pay more attention in class	4 (11.8 %)	6 (17.6 %)	24 (70.6 %)
	(E.2) Photographs gave me ideas, so I could easily participate in class discussion	1 (2.9 %)	4 (11.8 %)	29 (85.3 %)
Classroom Discussion with Peers	(F.1) Listening to other students' opinions helped me learn astronomy	2 (5.9 %	4 (11.8 %)	28 (82.4 %)
	(F.2) It was interesting to hear other students' ideas	2 (5.9 %	3 (8.8 %)	29 (85.3 %)
	(F.3) I don't see the value of discussion with peers, it just made me confuse[‡]	25 (73.5 %)	6 (17.6 %)	3 (8.8 %)

[†] Disagree = responses to "Strongly No" and "No," Agree = responses to "Strongly Yes" and "Yes"

[‡] This question is negatively asked

students *feel comfortable to participate in classroom discussion*, "I have felt more involved when using the clickers" (S15, Att#4). The *anonymous feature* of CRSs especially contributed to increase students' confidence in class, for example, "The clickers are awesome, now I don't get scared to speak up" (S3, Att#4). As a result, they could *learn from different perspectives by listening to their peers' various ideas* and it helped the teacher hear students' thoughts. For example, "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, Att#7), and "I got to learn more ideas than just mine so I could think about my answer more" (S12, Att#7).

Similarly, the pedagogical roles of the photographs are identified in this study, which are somewhat different from how they have traditionally been used in science classes. In traditional classes, they typically play a rather conservative role, while in the P+TEFA lessons, students actively engage with them in the learning process. In P+TEFA, photographs have three main pedagogical roles based on the *observation* of their *rich details* (Fig. 2).

Easing Students' Anxiety About Learning a New Concept

When the students saw a photograph, they were comfortable saying something about it. They could just describe

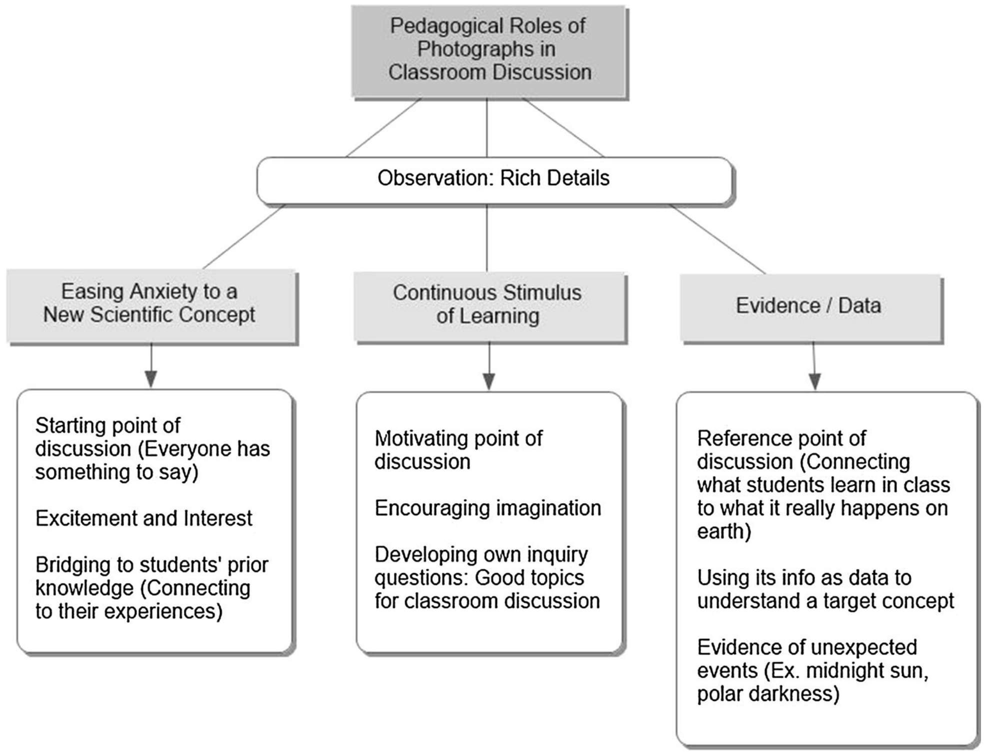

Fig. 2 Pedagogical roles of the photographs in classroom discussion

what they saw in it, which was not necessarily right or wrong. It became a good *starting point for discussion* because everyone had something to tell. This is well represented in the following quotes from Mary:

> 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 (Oct 30),

> and

> I think they [photographs] 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 (Nov 10).

This very beginning process helps relieving the students of any worry about learning something new. The students also mentioned that it was easy to participate in class when using the photographs, for example, "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-, Oct 7). As we noted above, not only did the photographs comfort the students, the students also enjoyed working with them. The rich details of the photographs provided the students with *excitement and interest* because looking at the photographs amused them. For example, "I did like the lesson because it's different from our normal learning and because we get to see pictures that look cool" (S9, Oct 20), and "The photographs are amazing and the world looks more fascinating than ever!" (S-, Oct 20).

As seen in the lesson vignette earlier in this article, the students often brought their prior experiences and knowledge when observing the photographs and they recognized themselves that the *photographs helped them connect the new concept with their prior knowledge.* For example, one student wrote "By seeing pictures on the screen, it helped me make connections in my head" (S31, Att#4). The photographs were a good starting point for discussion, gave the students excitement and interest, and helped bridge students' prior knowledge to new scientific concepts. These pedagogical roles help to ease students' anxiety about learning new scientific concepts.

Continuous Stimulus of Learning

Observing the photographs encouraged the students' learning in science. Not only in the beginning, but also during the discussion, the photographs *continuously motivated students' participation*. For example, Mary noted, "I think they [photographs] were very positive, … I think it really surprised them to find out what time of day or night it was in certain photos. They were very motivating" (Oct 24), "It [using the photographs] is one of the motivating points to get them engaged" (Oct 30), and "photographs were a great motivator. They really got kids thinking" (Nov 10).

Observing the rich details of the photographs encouraged students' *imagination.* As seen in the vignette, the students created their mental image of the earth in space with a bird's-eye view that was not provided in the photograph and they developed their reasoning from their mental image. They also mentioned in the survey that the photographs helped them use their imagination in the lessons, for example, "I liked everything about this lesson and thought it was fun because we could imagine!" (S15, Oct 14), and "it was great to have us use our imagination and what we know" (S8, Oct 9).

The rich details of the photographs were a great source for the students *to develop various inquiry questions* for classroom discussion. For example, the students brought up various questions when they saw a photograph of the earth seen from the moon. Some of their questions were

S3 If you fell where would you go, … if you fell and you jumped off the moon?
S1 Can you see any other planets from the moon?
S6 Why can't you see the stars in the sky?
S16 How come you can't see the sun?
S11 How long does it actually take to get to the moon?

Those questions were from their observation of the photograph and were great topics for classroom discussion. It somewhat resembles how scientists develop their research questions when they observe objects or phenomena.

Evidence/Data

During the discussion, the photographs served as a *reference point*. The photographs helped the students connect what they learned in class to what really happens on earth. Mary thought that the photographs helped the students connect their exploration with light bulbs and globes in class to what they can observe in reality on earth, saying,

> 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 (Oct 15).

As seen in the vignette earlier, the students obtained information by observing the photographs to answer CRS questions. For example, S5 thought that "The sun's going down" in the photograph A of Q1 (Table 1), and it was based on the information that he observed from the photograph, saying, "Because the sun is like higher in the sky and you can see the lights on the trees." During the classroom discussion, the students actively *searched for information in the photographs and used it as data to understand a target scientific concept*.

In the lessons, the photographs showed the natural phenomena, midnight sun and polar darkness, in relation to the length of daytime and seasonal change. The students recognized the photographs as being effective in demonstrating the *unexpected events as evidence*, saying, "The photographs helped me by how it shows me what everything looks like that I never expected" (S16, Att#5). This was possible due to the *rich details* of the photographs, "It showed me how it happens in real life and it made me think more open minded" (S9, Att#5), and "It helped me more by seeing the photos. I did not understand white night until I saw the photo" (S29, Att#8). This last pedagogical role of the photographs as data and evidence is most similar to how they are used in professional scientific research.

Discussion and Implications of the Study

Overcoming Naïve Conceptions and Increasing Scientifically Correct Conceptions via P+TEFA Pedagogy

Before discussing the differences in conceptual learning between the intervention and traditional groups, it is important for us to note that our study was not a controlled experiment due to the different amounts of the classes time on the topics. Therefore, we cannot claim that the use of P+TEFA caused the differences that we measured. That would require a controlled experiment, which we may do in the future. However, we feel confident that our data suggest that the use of P+TEFA led to larger reduction in the number of naïve conceptions and an increase in the number of scientifically correct responses in the intervention group when compared with the traditional group. That is, the P+TEFA pedagogy, which gives students opportunities to observe natural phenomena via photographs and to have discussions with peers, may be effective in helping the students to overcome primitive conceptions and in helping the development of scientifically correct conceptions. It concurs with previous literature that learning an abstract concept can be maximized through experiencing perceptually rich and concrete representations (Goldstone and Sakamoto 2003). In addition, these types of representations can be especially effective for novice learners when they begin to learn a new concept using their prior knowledge (Collins et al. 1989). Photographs as a concrete visual representation that presents the real world with perceptually rich details may be effective for students, especially in the beginning stage of learning, to scaffold a new abstract concept with their prior knowledge from daily experiences. In addition, as the students engaged in classroom discussion, they were able to encounter the different perspectives of their peers and to recognize flaws in their original conceptions. This coincides with Heywood, Parker, and Rowlands' conclusion that "the presentation of a range of alternative models generated by learners for the explanation of a particular phenomenon could provide an opportunity to generate further engagement and dialog to help learners better articulate their expressed models" (Heywood et al. 2013, p. 794). Sharing their ideas in discussion helped the students improve their understanding about the scientific concepts.

Teacher Support

The big challenges for Mary in implementing the P+TEFA pedagogy were facilitating classroom discussion and that it took longer to cover the material. Mary was an expert teacher, but even for her, performing a new role was not easy. It was her first time using the CRS technology and implementing the new pedagogy in her class. Even for a veteran teacher, it is no surprise that it took time to get familiar with the new technology and the pedagogy. This suggests that even expert teachers need help learning a new pedagogy before they initially implement it, and educational programs and policies should provide appropriate professional development support (Loucks-Horsley et al. 2003).

Photographs as a Way to Observe the World

Although photographs are ubiquitous in our daily lives, their application has been conservative in science classes. In our study, however, photographs played active pedagogical roles: *easing students' anxiety about learning a new scientific concept*, *continuous stimulus of learning,* and as *evidence and data.* These roles differ from how photographs had traditionally been used in science classes. Rather than being supplementary material with a top-down approach, the photographs in our study played a more active role in enhancing student learning with a bottom-up approach. Extraterrestrial photographs or diagrams are commonly used in astronomy textbooks to help explain natural phenomena, but our study implemented photographs that were seen on the earth, as we experience it everyday. While the photographs show what we observe daily, the lessons focus on investigating the scientific reason for the natural phenomena. The types of photographs that we used in our study when used in science classes can elicit students' preconceptions that have been arisen from daily experiences and can also be used to generate classroom discussion.

Lehesvuori et al. (2013) argued that teachers "must open up space for dialogic discussion in order to explore students' initial views or experiences" (p. 917). The photographs naturally elicit students' experiences and prior knowledge during discussions. Students' observation of the rich details of the photographs helps them to share their thoughts with peers, eases their anxiety of learning a new concept, and makes them feel comfortable to participate in discussions. During discussions, the students actively sought information from the photographs and used the data to ask and answer questions. This is somewhat similar to what scientists do in their scientific research. By observing the photographs, the students have a chance to observe the real world. They perceive the information that the photographs present, connect it to their prior knowledge, use the data to understand the phenomena by sharing their ideas in classroom discussion, and develop deep insights about how the natural phenomena are related to what they experience in their daily lives. Through this process, the students are able to overcome their naïve conceptions and develop scientific understanding.

There may be a limit to relying solely on photographs in instruction. As a static visual representation, photographs are limited in their ability to represent motion or three-dimensional images (Ardac and Akaygun 2005). Details in photographs may result in students focusing on unnecessary information and distracting them from the target concepts (Sloutsky et al. 2005). Students may misinterpret or may not recognize what the photographs are meant to represent, and they may come up with a non-scientific conclusion from the discussion of the photographs. In using photographs, it is important for teachers to lead students along the right reasoning track. In addition, supplemental hands-on activities or experiments may be required. However, our study suggests that implementing photographs in classroom discussions with appropriate pedagogy such as P+TEFA is one way of decreasing the gap between students' prior knowledge and abstract scientific concepts. Identifying which teacher moves would maximize student learning using P+TEFA remains future work.

It is important to provide opportunities for students to observe the real world so that they can connect their observations and experiences to abstract target scientific concepts. Photographs are often overlooked and have conservative roles in many science classes. They may need to be seen from a new perspective as active pedagogical materials with the *bottom-up* approach that can lead students from observing concrete examples to understanding abstract scientific concepts. As a last remark, we end the paper with one of the students' quotes: "Using what we already know and learning more is great!"

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