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Teaching to the Misconception: Critical Thinking and Pre-Service Elementary Teachers

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Abstract. Over the past few decades, numerous studies have demonstrated that pre-service and in-service teachers fall victim to the same misconceptions as the students they are or will be teaching. At the same time, research has shown that addressing the misconceptions head-on and leading students to a deep, personal understanding of why their previous conceptions were erroneous aids in replacement of misconceptions with an accurate understanding of the natural world. This paper demonstrates how this was accomplished in a required university-level Earth/space/physical science course for pre-service elementary school teachers, with an emphasis on examples from the Sun–Earth–Moon system.

1. Introduction

Numerous studies over the past few decades confirm that pre-service and in-service teachers hold many of the same misconceptions as their students regarding the Sun–Earth–Moon system, including the cause of seasons, lunar phases, and solar eclipses (e.g., Bisard et al. 1994; Comins 2000; Trumper 2001, 2006; Brunsell & Marck 2005; Kalkan & Kiroglu 2007). While the use of three-dimensional models (e.g. Stahly et al. 1999; Trumper 2006; Larsen & Bednarski 2013) and discussing common misconceptions in classes for pre-service teachers have demonsstrated some success, as reflected in the literature as well as the author's personal experience (Bisard et al. 1994; Comins 2000; Trumper 2001), there can too often be a 'back-sliding' to previous misconceptions by the end of the semester. These students are engaging in surface learning or rote memorization rather than deep learning (a permanent abandonment of personally held misconceptions). In the spring 2013 semester the author experimented with a new method of pedagogy in the Elementary Physical/Earth Sciences course, a required course for pre-service elementary school teachers. This new methodology centers around coupling the standard 3–D hands-on activities with a new pre/post-activity worksheet named PEOER: Predict – Explain – Observe – Explain – Reflect. The purpose of this methodology was to focus students' attention on their own understanding by having them reflect on what they know, how they know it, and how their understanding changes over the course of the instruction.

2. Methodology

In the spring 2013 semester the author utilized a new worksheet entitled PEOER with the students in this class. Students were informed that it was an experimental pedagogy and signed an informed consent form if they agreed to have their worksheets included in this study. Students individually signed an agreement for each of the three worksheets (seasons, lunar phases, solar eclipses). The course had 21 students. One student requested that none of her worksheets be included in the study. For the seasons worksheet one student's work could not be included because he/she was absent on the day the "pretest" portion was administered. For the lunar phases/solar eclipses worksheets, two students' work was excluded for the same reason. Therefore, the sample size was 19 for seasons and 18 for lunar phases and solar eclipses. Each worksheet had five questions:

1. Predict: The reason it is hotter in the summer is because... (The reason the Moon goes through phases is because... Eclipses of the Sun occur when...)
2. Explain: This is how it happens:
3. Observe: Using the models in class, I found:
4. Explain: This is how it happens:
5. Reflect:
    - I have had the following change in my understanding of this topic:
    - My previous understanding was due to...

For each topic, the students completed the first two questions two class periods before the topic was covered. It was decided to complete these questions two periods prior in case students read ahead in the textbook.

Before attending the class period when the topic was covered, the students were assigned textbook reading and completed basic homework questions on the topic. The worksheet questions as posed were not part of the homework. On the class date in question the students completed several standard hands-on activities and listened to a mini lecture by the instructor. They then completed the final three questions on the worksheet. For seasons, the activities included modeling the changes in the incident angle of sunlight using flashlights and a 3–D model of the Earth (essentially a spinnable ball on a tilted mount). For lunar phases and solar eclipses students used the classic Styrofoam ball on a stick and bare light bulb to model the cycle of phases and demonstrate that a particular alignment is required to generate eclipses (when the Moon casts a shadow on the Earth and vice versa). Several weeks later the initial predict question was asked again as part of an end-of-unit quiz, and the same question was repeated on the end-of-semester final exam. Student responses to these questions were coded on a 0–3 scale: **0** = no answer or an answer unrelated to the topic; **1** = a clear misconception; **2** = no misconception shown, but the answer was incomplete; **3** = complete, correct answer.

3. Results

Tables 1 and 2 summarize the results of this study. From Table 1 it is clear that there were gains in student understanding of all three topics from the pre-lesson response on the worksheet to the post-lesson unit quiz, and as a class these gains increased to the final exam. This second change would be due to feedback to students who had answered incorrectly on the quiz. Interestingly, seasons were not the topic with the lowest initial understanding, but rather Moon phases. Moon phases were also the topic with the lowest gains in student understanding. However, there was the greatest gain between the post-lesson quiz and final exam of any of the three topics, suggesting that 'getting it wrong' one more time was important in dislodging the misconceptions for some students. This suggests that the introduction of an additional 'pre-quiz' assignment might reinforce student understanding, especially for students who find the 3–D nature of lunar phases especially challenging or confusing.

Table 1. Student Scores over the Semester.

Topic	Pre-lesson response	Post-lesson quiz	Final exam
Seasons	1.15	2.21	2.37
Moon phases	1.0	1.17	1.78
Solar eclipses	1.68	2.49	2.61

Table 2 summarizes the gains achieved by individual students. The vast majority of students improved their understanding of seasons over the semester and sustained this gain through the final exam. Gains in understanding solar eclipses were found in just over half the students, but it should be pointed out that this is the topic with the highest initial understanding. The overall gains in Moon phases are also around 50% through the final exam, reflecting the apparent difficulties students have with this topic. Of concern was the nearly quarter of students who improved from the initial pre-quiz to the quiz, and then reverted to previous misconceptions or incomplete descriptions by the final exam, as well as the 16% of students who actually began the series with at least a partial understanding of the phenomenon but regressed to misconceptions after participating in this pedagogy. A similar phenomenon was also seen in Larsen and Bednarski's study (2011) of the use of 3–D models and full-dome digital planetarium shows in teaching these same topics to elementary school children, suggesting that 3–D models are the source of the 'new' misconceptions rather than the worksheet itself.

Table 2. Change in Individual Students' Understanding over the Semester.

Topic	Improved	Improved then regressed	No change	Regressed
Seasons	84%	5%	0%	11%
Moon phases	56%	28%	0%	16%
Solar eclipses	56%	5%	28%	11%

Another measure of the relative success of this pedagogy is a comparison of the scores on the final exam to classes taught in past semesters, but data only exists in the case of lunar phases and seasons, and only for the preceding three semesters. For seasons, the percentage of complete correct answers was 24%, 41%, and 37%, respectively, for the preceding semesters and 53% for the semester in question, an apparently significant difference. For lunar phases, the results are 19%, 27%, 0%, and 28%; no clear trend can be claimed in this case.

4. Other Findings

Misconceptions were sometimes not seen in the student responses to the initial Predict prompt but turned up in the first Explain section. For example, students may predict that the seasons are caused by the tilt of the Earth, but later add that this tilt makes a portion of the Earth closer to the Sun, causing it to be warmer than the rest of the Earth. Some students were able to give a verbal explanation but drew optional pictures that demonstrated misconceptions or vice versa. The takeaway message is that multiple choice and fill in the blank type questions may hide misconceptions (as they often rely on surface learning or memorization). Another finding was one noted by other authors (e.g., Trumper 2006; Kalkan & Kiroglu 2007) that the most common misconception seen was that seasons are caused by the Earth's changing distance from the Sun. In the case of this study, 90% of students initially voiced a misconception about seasons; all but one of these students included the Earth's distance in their faulty explanation.

Individual students gave rather interesting responses, revealing a variety of personal misconceptions. For example, for Moon phases one student predicted that the cause was, "the sky is darker during each phase," explaining that it happened through "the rotation of the planets." Another student predicted that phases have "something to do with tides," but noted that he/she had "not the slightest clue, sadly" how this might happen. A third student predicted that "the Moon goes through phases because of the position of the Sun and the location of the clouds," explaining further that "this happens because the Moon rotates and the view of the Moon's different at different geographical locations." Another student predicted that solar eclipses occur as "the Sun creates more light and allows an eclipse to occur." He/she explained that this occurs because "the Moon goes through phases and has different temperatures of sunlight, as the temperature increases more sunlight is produced to show the eclipse." Another student responded that a solar eclipse occurs when "the Sun goes in front of the Moon and it changes how we see the Moon at night." In his/her view, "this happens at night, it must get darker and the Moon comes out. It always looks different because of where the Sun is on it."

While it is fairly obvious in the case of this last misconception that the source is related to a misunderstanding of the geometry as well as a confusion between eclipses and phases, the sources of some misconceptions are not obvious to pinpoint. For example, one student predicted that solar eclipses occur when "the Sun lines up with Mars." She further explained that "there is a time every couple years on the Sun's cycle." The source of her misconception would normally remain a mystery to the instructor, except that in the PEOER method the student is asked to reflect on how their understanding has changed, and what the source was of any initial misconceptions. This student reflected, "Since the solar eclipse appears red, I thought it had to do with Mars, since Mars appears red in the sky." Was this student confusing a picture of a solar eclipse (with the reddish-pink chromosphere) with a picture of a reddish lunar eclipse as well as the appearance of Mars? If so, then instructors should take care when describing the appearance of lunar eclipses and carefully contrast this to the appearance of solar eclipses including the chromosphere and corona (not merely saying that a lunar eclipse appears red). This is especially important if the textbook has pictures of both types of eclipse printed side by side.

5. Conclusions

The PEOER method appeared to result in a measurable improvement in the students' understanding of seasons, lunar phases, and solar eclipses, and an improvement that was sustained over the course of the semester. It is important to note that the improvement was markedly less for Moon phases, suggesting that perhaps more attention should have been paid to this topic, including additional hands-on activities. However, the sample size in this study was admittedly small (18/19 students, depending on the activity) so further data certainly needs to be collected. The students appeared to enjoy using the worksheets, and only one student declined to have their work be included in this voluntary study; therefore, the author encourages others to adapt this methodology for their own use and share the results.

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