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The Seasons Explained by Refutational Modeling Activities

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Abstract

This article describes the principles and investigation of a small-group laboratory activity based on refutational modeling to teach the concept of seasons to preservice elementary teachers. The results show that these teachers improved significantly when they had to refute their initial misconceptions practically.

1. INTRODUCTION

The concept of seasons is difficult to understand, and misconceptions are hard to dispel. Several studies have shown that the main misconceptions about seasons involve the belief that seasons are explained by the varying distance between the Earth and the Sun (we refer to this as the "distance hypothesis") or the belief in an oscillatory movement of the rotation axis (Atwood & Atwood 1996; Sebastia & Torregrosa 2005). More precisely, regarding the first misconception, students answer that it is hotter in summer because the Earth is closer to the Sun. Following the same reasoning, it is colder in winter because the Earth is farther from the Sun. This misconception is reinforced by the commonly exaggerated representation of the elliptical path of the Earth around the Sun. For the second misconception (which we refer to as the "tilt oscillation hypothesis"), students believe that the direction of the axis is not constant and points alternatively more toward, or more away from, the Sun in an oscillatory movement. This misconception might also come from the fact that in some representations, the Earth is seen in two positions—summer and winter solstices—but with a different inclination of the rotation axis.

Usually, to teach the season concept, one presents the scientific facts, which may or may not be supported by hands-on methods. We have tested a new way of modeling seasons that appears to go beyond the usual misconceptions very efficiently. This modeling is based on a refutation activity, which was carried out in a small-group laboratory setting. More precisely, we asked groups of students to model several hypotheses about seasons to find arguments for supporting or refuting them. The educational objective of our method was to teach the concept of seasons by showing why the misconceptions did not fit. In this article, we present the material, the setting of the activity, and the results of the investigation of this method with 20 preservice elementary teachers.

2. MATERIAL NEEDED AND SETTING

The activity can be completed without much material or going to much expense. We need only to represent the Sun and the Earth. We used a lamp for the Sun and a nontilted globe for the Earth (a ball can also be used). The globe should be not too big (about 15 cm in diameter; Figure 1), and the lamp should be large and strong enough to correctly simulate night and day on the Earth (Figure 2). In fact, the best solution we found was to use a lamp from a video or slide projector (Figure 3). We also used a piece of string as a means of measuring the relative length of day on the globe (Figure 1). The string must be placed on a parallel of the Earth and then divided into 24 equal segments with ink marks to represent the 24 time zones. To divide the string, we can follow the time zone longitudinal lines printed on the globe itself, or we can take the string off the globe and divide it by folding it in three, and then in half three times. Each fold is marked by ink. In fact, the division of the string is not very important, and the activity can be performed with a nondivided string; what *is* important is that students can note the relative length of the lit string (corresponding to daylight) versus the nonlit string (corresponding to night). They can then make the link between length of day relative to length of night and the seasons, the axis tilt, and the location on Earth. We chose the parallel of Toulouse, France. This choice can be adapted depending on where the students live. We also put a piece of string on the equator and on the parallel of Sydney, Australia. An instruction sheet can be used to direct the students through the modeling activities, and some information about seasons can be provided. One prerequisite for the students is the knowledge that the Earth’s rotation takes 24 hours and that it revolves around the Sun in one year.

Figure 1. The globe (diameter about 15 cm) used with the graduated string on the Toulouse, France, parallel.

Figure 2. The lamp used (diameter about 15 cm).

Figure 3. The slide projector used.

Students worked in groups of four or five. We chose to form heterogeneous groups to facilitate cognitive conflict and discussion with peers. No safety precautions are necessary. The modeling activity took between 45 minutes and 1 hour. A globe with strings already in place and a lamp were given to each group.

2.1 Instructions Given to the Students

Students were given the following instructions:

"You are going to model three hypotheses to explain seasons:

- The Earth is closer to the Sun in summer and further away in winter (*distance hypothesis*)
- The rotation axis oscillates (changes direction in space during the year) (*tilt oscillation hypothesis*)
- The rotation axis is tilted but keeps a fixed direction in space (accepted hypothesis).

With regard to information about seasons, which of them can or can't fit and why?"

To model and be able to refute or confirm the hypotheses linked to the axis tilt, we also proposed an explicit test of the effect of no tilt to the rotation axis, followed by the modeling of a fourth hypothesis: "The Earth's rotation axis is not tilted."

The previous hypotheses can be proposed directly or preferably derived after questioning the students' prior knowledge. We could either give out documents with the information shown in Appendix A, or ask the students to produce them, depending on the time available. We used both methods. If students are asked to produce the information, additional time of about 15–30 minutes is required for documentary research in which they look for, assess, and use outside sources of information (e.g., books, the Internet, and so forth). During the activities, we also gave the values of the distances between the Earth and the Sun for winter and summer solstices to enhance the refutation of some hypotheses (mainly the first one). Students could observe that the Earth is closer to the Sun when it is winter in the northern hemisphere.

If needed, the instructor can help groups by asking a few questions and serving as a moderator. For instance, for the first hypothesis, the moderator can ask, "If you change the distance between the Earth and the Sun, does it act on the parameters given in the documents in the expected way?" For the second one, "If you change the tilt of the Earth, does it act on the parameters in the expected way? How can we find the north at night without a compass on a clear night? What does this hypothesis imply for the north direction during one year?" And for the third, "Why are days longer in summer than in winter in the northern hemisphere? Use the graduated band on the globe. If the axis were not tilted, evaluate the length of day relative to the length of night. What can you conclude?"

More precisely, the moderator is present to enhance the activity if the students are lost or having difficulty understanding the task. Nevertheless, because the objective of our configuration of small groups for this refutation activity is to facilitate the cognitive conflict and the construction of knowledge with peers, the instructor should have a minor role. He or she should help groups by asking a few questions or explaining how the material can be used, but only when necessary. Practically, we observed that it was very rare that the instructor had to say something, and the activity was well understood and conducted by the groups of students without external intervention.

2.2 Diagrams for the Modeling of Each Hypothesis

Following are descriptions of the modeling activities for the four hypotheses discussed.

a) Hypothesis that the Earth is closer to the Sun in summer and farther in winter (distance hypothesis; Figure 4):

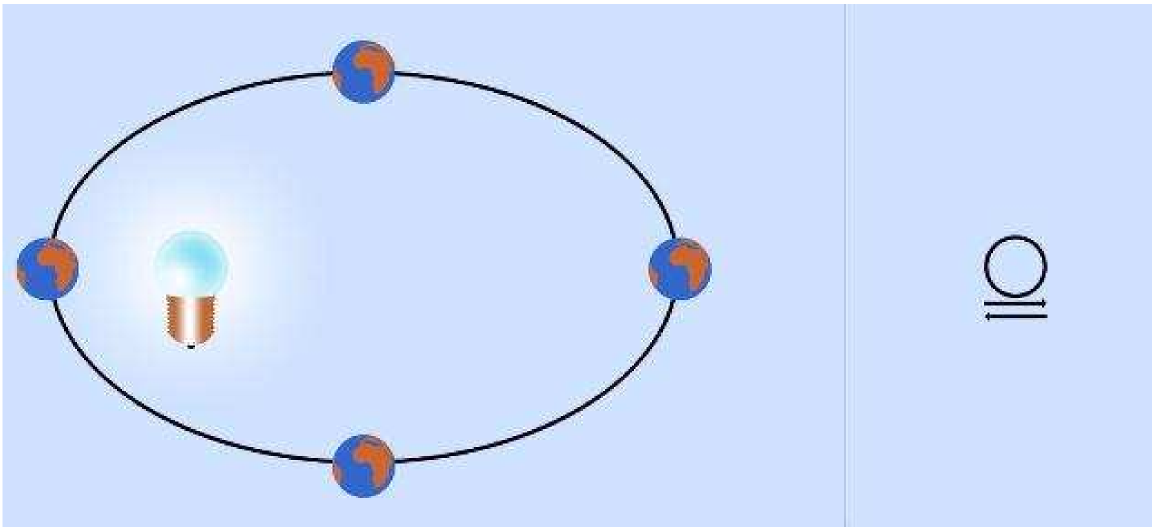

Figure 4. Modeling of the distance hypothesis. No consideration of the tilt.

b) Hypothesis that the rotation axis is not tilted (Figure 5):

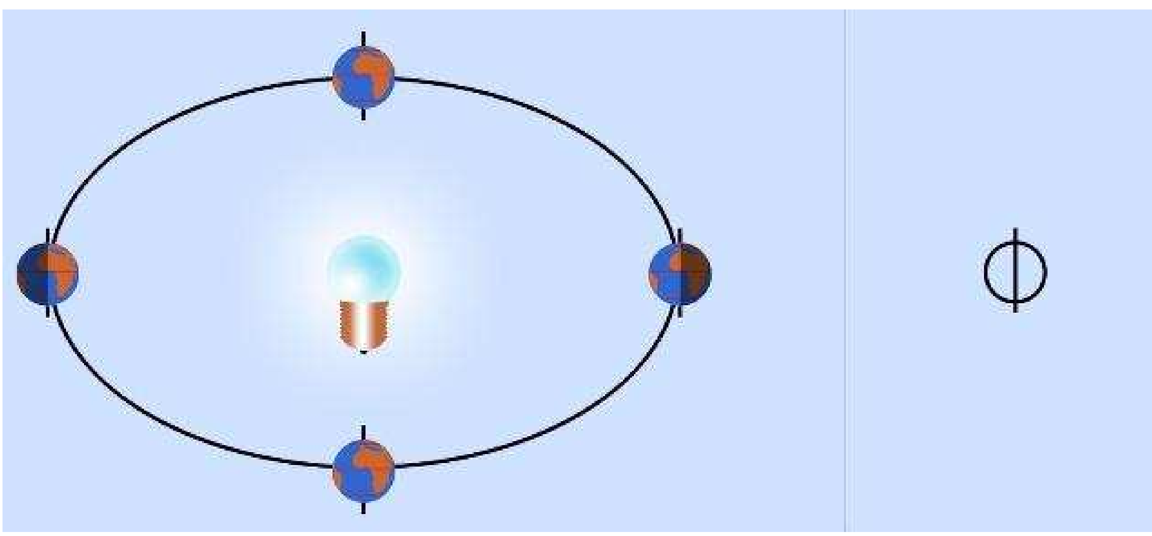

Figure 5. Modeling of an absence of tilt. Three strings are placed on the parallels of Toulouse (France), the equator, and Sydney (Australia) for the measures of the lengths of day for the solstices' positions during the revolution of the Earth.

c) Hypothesis that the rotation axis oscillates (tilt oscillation hypothesis; Figure 6) :

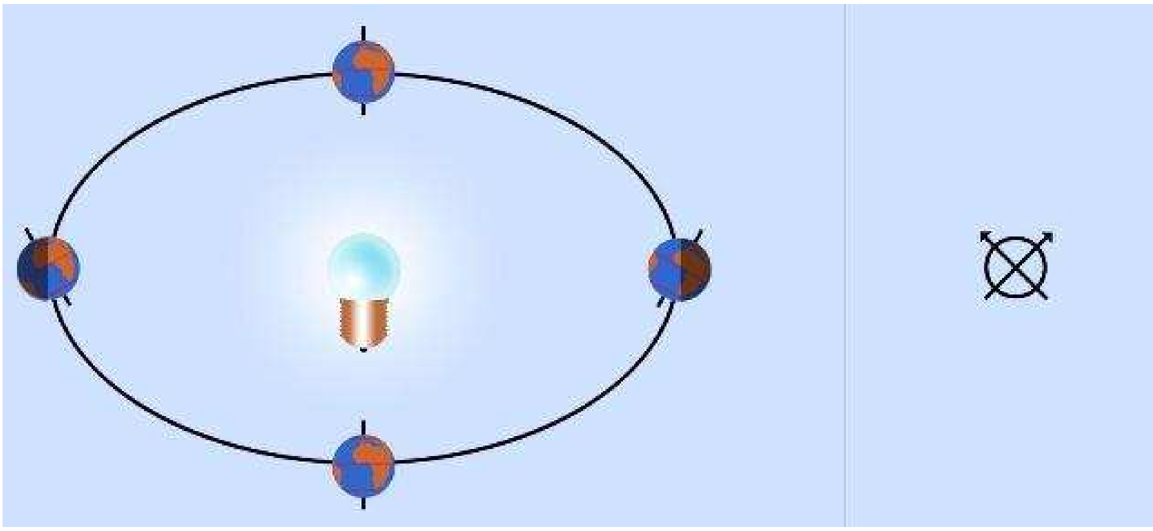

Figure 6. Modeling of an oscillatory movement of the axis. Three strings are placed on the parallels of Toulouse (France), the equator, and Sydney (Australia) for the measures of the lengths of day for the solstices' positions during the revolution of the Earth.

The three misconceptions described in the three hypotheses (models) are very common and very resistant. They can thus be refuted thanks to experience, a confrontation with modeling, and the information shown in Appendix A. To address these different misconceptions, each model was tested by the students either to measure length of day or to observe how the Earth is lit. Students just made the Earth revolve around the Sun. For certain positions (namely the solstices and equinoxes), they measured the relative part of night/day on the different strings, and they observed the differences between the northern and southern hemispheres each time by comparing observations (modeling) and data in the documents.

Indeed, the distance hypothesis, whereby the variation in the Earth's distance from the Sun between summer and winter produces seasons, is easy to refute thanks to information about the inversion of the seasons between hemispheres; when it is summer in France, it is winter in Australia. Students demonstrated that it would be hotter everywhere at the same time on Earth, thus refuting the distance hypothesis. The exact distances between the Sun and the Earth at solstices give further support to refuting this conception, regardless of students' beliefs about the tilt of the Earth. Moreover, if they changed the distance between the Earth and the Sun in their model, they observed no difference between the length of day and the length of night from this manipulation only. All these observations contradict the information given in the documents.

Regarding the second model, if the axis were not tilted, students would not observe any variations in the length of day relative to the length of night during the revolution of the Earth around the Sun. But from the documents and their personal experience, students knew that the length of day increases in summer and decreases in winter relative to the length of night. So, they concluded that if the axis were not tilted, the length of day would not change, and all locations on Earth would have 12-hour days and 12-hour nights.

Finally, the last hypothesis, related to the oscillation of the rotation axis, would have a direct consequence: The length of the day would not vary, as students' experience and documents show. The students made the Earth revolve around the Sun, and they made the axis oscillate at the same time, observing that it is impossible to recreate the four seasons. Indeed, the same place on Earth would have winter or summer twice in the same year.

Thanks to this confrontation with modeling and documents, misconceptions can be revised and given up.

d) Hypothesis of a constant tilt of the axis (Figure 7):

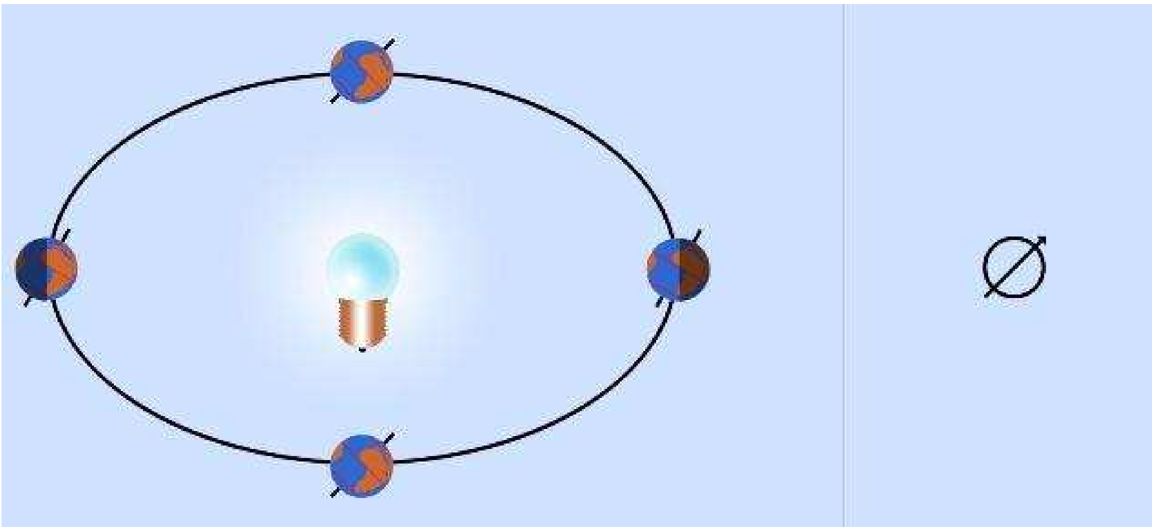

Figure 7. Modeling a constant tilt of the axis. Three strings are placed on the parallels of Toulouse (France), the equator, and Sydney (Australia) for the measures of the lengths of day for the solstices' positions during the revolution of the Earth.

This modeling is compatible with all the information given in the documents and the different measurements obtained by observing the strings. Students moved the Earth in the four positions corresponding to solstices and equinoxes, and they observed that the relative part of night and day acted in the correct way and was consistent with the differences between the two hemispheres.

3. RESULTS

We have investigated these refutation activities with several groups of preservice elementary teachers (Figure 8). We will present some results on 20 participants (five groups of four students).

Figure 8. A group of students measuring the length of day on Earth relative to the length of night, with the help of the string.

The students were asked several questions about seasons before the activity, one day after the activity, and 30 days after the activity (pretest, immediate posttest, and delayed posttest; questions are shown in Appendix B). We were interested in collecting their misconceptions, and seeing their evolution after the activity and the long-term effects.

3.1 Evolution of Misconceptions

We have selected three questions to illustrate the evolution of the misconceptions. One question is related to the reason that it is hotter in summer than in winter where they live (Toulouse; Question 1 of Appendix B). The second question deals with the reason that there are different seasons each year (Q3 of Appendix B). The third question concerns the length of day depending on the season (Q5 of appendix B). The students' misconceptions were mainly linked to the idea that there is a varying distance between the Earth and the Sun and to the belief that the rotation axis oscillates. Table 1 shows the global percentage of answers for the pretest (P), immediate posttest (IP), and delayed posttest (DP). The answers are put into three main categories: the usual misconceptions categories (varying distance between the Earth and the Sun, and the tilt oscillation); the correct answer category (associated with the constant tilt of the rotation axis); and a category that contains the absence of answers and the rare answers. For instance, these answers can be that the Sun produces more energy in summer than in winter, to explain the temperature difference between summer and winter, or that the Earth has a tilted rotation axis of 90° on the orbit plane, to explain seasons. This last misconception indicates that students know that the rotation axis is tilted but do not understand the value meaning.

Table 1. Percentage of Answers (N = 20) for Three Questions

Category of answer	**Varying distance between the Earth and the Sun (distance hypothesis)**			**Tilt oscillation hypothesis**			**No answer or other (Sun energy, or wrong tilt value…)**			**Right answer (constant tilt)**		
	P	IP	DP	P	IP	DP	P	IP	DP	P	IP	DP
Qa	30%	0%	5%	30%	0%	0%	0%	5%	5%	40%	95%	90%
Qb	35%	0%	5%	30%	0%	10%	5%	0%	0%	30%	100%	85%
Qc	20%	0%	0%	10%	0%	10%	10%	5%	10%	60%	95%	80%
All questions	28%	0%	3%	23%	0%	7%	5%	3%	5%	44%	97%	85%

Qa: Why is it hotter in summer than in winter in Toulouse?
Qb: The different seasons that we observe each year are mainly due to. . .
Qc: Why are days longer in summer than in winter in France?

There are three main categories of answers: usual misconceptions (the idea that the distance between the Earth and the Sun varies and tilt oscillation belief); rare misconceptions (reported as no answer or other); and the right conception (constant tilt of the rotation axis, last column of table). For each category, the percentage of answers in the pretest (P), immediate posttest (IP), and delayed posttest (DP) are given.

We observed that for each described question, the majority of the students improved their understanding in a long-lasting way and abandoned their misconceptions after refutation modeling—more precisely, when they modeled that misconception and demonstrated why it could not work. These results show that the activity had an effect on the evolution of students' misconceptions by helping them revise and give them up in favor of the accepted conception. Indeed, from pretest to posttest, the percentages of accepted conception increased for each question, whereas the percentages of misconceptions decreased. If we consider all questions together (last line of Table 1), we observe that the misconceptions were common to more than 50% of the sample in the pretest (23% thought that the distance between the Earth and the Sun varies, and 27% thought that the tilt of the rotation axis oscillates), and only 43% gave the correct answer.

The refutation modeling activity had a strong impact; just after the activity, the percentage of wrong answers decreased to about 3%, and the correct answer percentage reached about 97%. For the delayed posttest, those percentages remained quite similar, indicating robustness in the evolution of the conceptions. Indeed, after refutation of those two misconceptions, only around 10% maintained their incorrect notion in the delayed posttest.

If we look at the preservice teachers individually, very few of them did not improve in a lasting way. For instance, Claire changed her misconception from "tilt oscillation" in the pretest to "distance" in the delayed posttest, and Myriam returned to her initial misconception, tilt oscillation, in the delayed posttest. Except for those isolated cases, the move from a misconception to the accepted conception was the observed rule. All the participants showed a real interest in the activities, and the discussion with peers inside the groups showed that they were all very involved in the activities. We have tested this method with several groups of adults, and it was relevant each time.

3.2 Statistical Results

We present some statistical conclusions derived from this investigation. The pretest and posttests consisted of multiple-choice questions directly related to seasons. (For a detailed description of the questions and scoring key, refer to Frede, in press, which presents a comparison of methods, including refutation activities [reading and modeling], for teaching astronomical concepts). Here we focus on the five questions described in Appendix B.

The students' mean scores for the pretest questionnaire was 2.25 (out of 5). It increased to 4.35 in the immediate posttest and 4.05 for the delayed posttest. Analyses of variance showed a significant effect of the refutational modeling on the scores globally, $F(2) = 17.250$, $p < 0.001$. More precisely, the differences appeared between pretest and immediate posttest, $F(1) = 29.766$, $p < 0.001$, and between the pretest and the delayed posttest, $F(1) = 16.052$, $p < 0.001$. Nevertheless, we observed no significant difference between the two posttests. We confirmed our qualitative results: that the conceptions of the preservice teachers changed in a lasting way and that they abandoned their misconceptions after the modeling refutational activity.

4. CONCLUSION

We tested a refutational modeling activity to teach seasons and observed that it was efficient in producing conceptual change in a lasting way. The preservice teachers questioned lost their misconceptions by modeling and refuting them explicitly. Globally, we showed that even for adults, collaborative hands-on refutation activities (modeling by small group and discussion) generate an increase in understanding. They provide the possibility to activate the prior knowledge of the learners and to question, experiment with, and refute it practically. We think that the results of this modeling activity can be important from an educational perspective because they demonstrate the potential effect of instruction type on the knowledge acquisition process and conceptual changes (Posner et al. 1982; Vosniadou 1991). Moreover, we expect that this refutation method can be adapted or extended to other concepts, learners, and teaching practices, such as demonstrations.

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APPENDIXES

Both appendixes are PDF files.

Click here for Appendix A, Information Used or Produced by the Students.

Click here for Appendix B, Questionnaire.

URLs

Appendix A: http://aer.noao.edu/auth/FredeAppendixA.pdf

Appendix B: http://aer.noao.edu/auth/FredeAppendixB.pdf