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Towards a Learning Progression Addressing the Causes of the Seasons: A Comparison of Two Learning Trajectories for Middle School Students

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Abstract

This study explored the development of a learning progression which addresses explaining the seasons. First, we investigate the importance of contextualizing instruction by comparing two learning trajectories. In the "local-first" trajectory students began by moving through major concepts from their own local perspective and in the "global-first" trajectory students worked through the same concepts but focused on comparing locations across the globe. Pre- and post-instruction assessments were analyzed for eighth grade students who participated in the "local-first" curriculum (two classrooms; N=18) and the "global-first" curriculum (three classrooms; N=21). While students showed significant improvement in their understanding of the seasons across both conditions, no differences were found between conditions. Using an item response modeling approach (*ConstructMap;* BEAR Center, 2009), person proficiency measures and item difficulty measures were calculated in reference to a scaled understanding of the seasons. The outcome of conceptual difficulty was used to revise our hypothetical learning progression and support the importance of addressing lower levels of sophistication before addressing the explanatory tilt model for the seasons.

Keywords: astronomy, secondary education, learning progressions, standards

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Introduction

One of the central concepts of astronomy experienced by many students is the changing of the seasons; yet extensive research has demonstrated the prevalence of misconceptions about this conceptual area (e.g. Atwood & Atwood, 1996; Baxter, 1989; Kikas, 1998; Sharp, 1996) and the resistance learners have towards developing full understanding (e.g. Kikas, 1998; Schneps & Sadler, 1988). The most commonly held misconception about the seasons is the use of the distance between the earth and the sun (either with the earth moving closer or farther from the sun or having the earth tilt closer/farther from the sun) to explain seasonal change (e.g. Schoon, 1995). Several other alternative ideas also contribute to the challenge children and adults have in learning to explain the seasons such as lack of understanding that the sun's apparent daily path changes across the seasons (Plummer, 2009) or belief that the earth's orbit is highly elliptical (Kikas, 1998; Schneps & Sadler, 1988).

The phenomenon known as the seasons is the result of the directly observable change in the path of the sun which causes changes in the intensity of sunlight (more intense when sun is higher in the sky resulting in increased temperatures) and changes in the length of day (longer days when the sun's path is higher and longer resulting in increased temperatures). These changes in the sun's path are the result of the tilt of the earth on its rotational axis with respect to the plane of its orbit around the sun. This tilt remains constant with respect to the background of stars. Because of this constant tilt and the shape of the earth, observable changes in the sun's path and the accompanying seasonal effects alternate with the northern and southern hemisphere. Project 2061 Benchmarks for Science Literacy (*Benchmarks;* American Association for the

Advancement of Science, 2009) propose that students should learn the following about the seasons by the end of 12th grade:

> Because the earth turns daily on an axis that is tilted relative to the plane of the earth's yearly orbit around the sun, sunlight falls more intensely on different parts of the earth during the year. The difference in intensity of sunlight and the resulting warming of the earth's surface produces the seasonal variations in temperature. (4B/H3*** (BSL))

Prior to this, *Benchmarks* proposes that students in the middle grades study phenomenon that influence the seasons: the influence of thermal energy transferred by ocean currents, temperatures in a given location have predictable patterns over the year and tend to relate to distance from the equator, and the number of hours of daylight and the intensity of sunlight vary predictably, both daily and yearly, in relation to distances from the equator and explains yearly temperature variations.

Recent studies have documented successful instructional approaches towards teaching the seasons, though not all approach the idea of "learning about the seasons" with the same depth as *Benchmark*. A quasi-experimental longitudinal study lends support to the use of conflict maps (a strategy for cognitive conflict) in improving middle school students' understanding of the seasons (Tsai & Chang, 2005). A curriculum designed around the use of kinesthetic learning techniques has also been shown to be successful for middle school-aged children (Slater, Morrow, & Slater, 2008). Pre-service teachers who spent significant time collecting, analyzing, and modeling observational data related to seasonal change improved their understanding over other students learning the seasons using traditional approaches (Trumper, 2006). Technologically-enhanced environments have also been shown to improve understanding of the seasons. In a study of high school students using computer-based animations and simulations, Hsu found that student-centered instruction was more successful than teacher-guided instruction (2008). Another study used 3D computer modeling to support students using a predict-observe-explain strategy to investigate the seasons resulting in modest improvement in student understanding (Kucukozer, Korkusuz, Kucukozer, & Yurumezogiu, 2009).

Comparison studies in learning the seasons have found benefits in inquiry-based over traditional instruction (Trumper, 2006), learner-centered over teacher-directed instruction (Hsu, 2008), and conflict map over traditional instruction (Tsai & Chang, 2005). We propose an additional comparative element: the role of contextualized introductory lessons in framing the seasons for students. A fair number of curricular resources utilize the structure of case studies in order to support middle school students' understanding of complex phenomenon (e.g. Ecology and Evolution, NSTA Press, focuses on Galapagos Island organisms to study ecology; Matter and Molecules, Michigan State University, utilizes the substance water to build students' knowledge of kinetic molecular theory). Resources like Everyday Science Mysteries: Stories for Inquiry-Based Science Teaching also use an analysis of phenomenon in one particular locale or context to consider the complexities of the natural world. Furthermore, certain curricular models draw upon the power of case studies and local context to engage students in learning about scientific concepts (e.g. Expeditionary Learning Schools model of "learning expeditions"). These approaches to the structure of curricula imply that students may benefit from learning about phenomena through a personal or local lens that allows greater connection to the concepts at hand. If a student can master an explanation of phenomenon observed from a primary locale, then the student may be better equipped to explain the impact of this phenomenon in other locales or contexts. Students may benefit from a “local first” perspective as they build on prior knowledge from their personal experiences allowing them to begin with an integrated network of seasons concepts. As new ideas are introduced, students may find these more acceptable and useful based on this existing framework. In designing the structure of lessons for this comparative study, we considered how the local-first construct might impact students' ability to explain the cause of seasonal change. Referencing other curricular resources that build on students' awareness of local phenomena and case studies, we wondered if students who were first able to explain the cause of seasonal change that they experienced annually would be better equipped to synthesize worldwide seasonal effects.

Learning Progression Framework

One of the challenges affecting progress in improving scientific literacy is that school science frequently tends towards disconnected facts rather than a designed focus on conceptual goals that build over time (Corcoran, Mosher & Rogat, 2009). We locate this study of children learning about the seasons in a learning progression framework because such research provides a way to develop long-term empirically based organizations of concepts towards big ideas in science. Learning progressions (LPs) are hypothetical descriptions, based on empirical research, about how students understanding of big ideas in science become more sophisticated through targeted instruction across time (Duschl Schweingruber, & Shouse, 2007; Smith et al., 2006). By designing instruction around big ideas, curriculum developers can move science education away from rotate memorization and disconnected concepts and towards integration and application of big ideas. Big ideas hold broad explanatory power in the domain, make connections across isolated concepts, and are developed over time as learners understanding them in increasingly sophisticated ways (Duschl, Schweingruber, & Shouse, 2007; Smith et al., 2006). LPs are considered to be hypotheses to be tested (Anderson, 2008; Stevens, Krajcik, & Delgado, in press); a students' prior knowledge and skills as well as variations in instruction will alter how a student will progress along a given LP. As students will not reach scientific understanding of big ideas without targeted instruction, a major goal of LP research is to identify instructional practices that will move students towards more sophisticated levels of understanding. Empirical data, based on student performance through instruction, should then be used to validate LP construction.

In the study we present here, we develop and test “learning trajectories” (LTs) based on the cause of seasonal change to set the stage for future work to build a full description of a learning progression. The mathematics education community has employed the use of LTs to describe how children may move along a path towards goals in a specific mathematical domain through a proposed instructional intervention (e.g. Gravemeijer, 2004; Simon & Tzur, 2004). The construction of these LTs is similar to the process of creating learning progressions; as with learning progressions, a hypothetical LT is designed around learning goals, targeted activities, and a description of how students’ thinking will develop in the context of the proposed instructional environment (Simon, 1995; Clements & Samara, 2004).

We have found LT to be a useful construct in describing our work in astronomy because the focus is on a smaller grain-size than other learning progression work while still allowing us to carefully build our empirical findings towards a full learning progression (Duschl, et al., 2007; Plummer & Krajcik, 2010; Smith, et al., 2006). The work we present here is part of a larger effort to build a learning progression for one of the big ideas in the domain of astronomy: celestial motion (Plummer & Krajcik, 2010; Plummer & Slagle, 2009a, 2009b). By “celestial motion” we refer to observable patterns of change in phenomena that result from underlying rotational or revolutionary motions of celestial objects. The motions of celestial objects in our solar system can be used to explain many observable phenomena in astronomy, including daily apparent motion of celestial objects, phases of the moon, and the seasons.

Project 2061's unpublished clarifications to the Atlas of Science Literacy, Volume II (Atlas; AAAS, 2007) for the key ideas for seasons suggest an effective conceptual ordering for this topic (a "global first" learning trajectory). These Atlas documents recommend that students first explore temperature variations, day length and sunlight intensity changes for different locations on Earth. Then, students should integrate their understandings of these patterns with the three-dimensional Earth-Sun system. The LT culminates with an explanation of the causes of seasonal change which connects the earth's daily rotation on its axis relative to the plane of the yearly orbit to variations in the temperatures across the earth's surface.

We propose an alternative LT ("local first") to compare against the Project 2061 conceptual trajectory. In the "local first" LT, students begin their analysis of temperature variations, day length and sunlight intensity changes for their local environment only. Students then utilize this locally based information to explore the three-dimensional model of the Earth-Sun system. From this, students build an explanation for the causes of these local seasonal changes. Students then use this working model of the Earth-Sun system to explain temperature and light variations for different locations on the Earth. As we argued above, we hypothesized that students who follow the "local" LT will more readily build an understanding of the cause of seasonal change than students who follow the "global-first" learning trajectory suggested in the Atlas clarifications.

Ultimately, testing these learning trajectories is part of an overarching goal to test how a learning progression, which culminates in the scientific understanding of the seasons, can be built upon previous learning progression research in astronomy (connections will be explored later in this paper). We therefore propose the following, overarching hypothetical learning progression:

1. *Naïve astronomical knowledge* - Students at this level may not apply the concept of the earth's rotation to explain the rising and setting of the sun or understand that the earth orbits the sun.
2. *Naïve seasonal knowledge* - Students responses do not reflect knowledge of the scientific concepts associated with seasonal changes such as the pattern of change of the sun's path or the earth's tilt. Students use alternative conceptions in their explanations for seasonal change, typically connecting change in distance with change in temperature. Students at this level are able to use the earth's rotation to explain the apparent motion of the sun and can describe the earth's orbital motion.
3. *Incomplete application of tilt without observational understanding*: Students at this level are familiar with the idea of tilt causing seasons[fragment of scientific concept] but they do not accurately apply this to local changes in the sun's path (altitude and length of day). These students do not connect changes in altitude and length of day to the changes in the seasons.
4. *Scientific – local* - The local phenomenon known as the seasons is the result of the directly observable changes in the path of the sun. These changes are the result of the tilt of the earth on its rotational axis with respect to the plane of its orbit. The earth's orbit is approximately circular.
    a. Misconception/lack of knowledge that differentiates from next level of sophistication: Lacks understanding that the shape of the earth results in opposing changes in the sun's path results in alternating seasons in the hemisphere.

   b. Sub-level: Accurate use of the tilt model to limited expression of the observational changes in the sun's path.

5. *Scientific –global* - The global phenomenon known as the seasons (alternating summer and winter in the northern hemisphere) is the result of the directly observable change in the path of the sun which causes changes in the intensity of sunlight (more intense when sun is higher in the sky resulting in increased temperatures) and changes in the length of day (longer days when the sun's path is higher and longer resulting in increased temperatures). The changes in the sun's path are the result of the tilt of the earth on its rotational axis with respect to the plane of its orbit around the sun. This tilt remains constant with respect to the background of stars. Because of this constant tilt, and the shape of the earth, observable changes in the sun's path and the accompanying seasonal effects alternate with the northern and southern hemisphere.
   a. Sub-level: Accurate use of the tilt model to a globally accurate knowledge of seasonal change but the expression of the observational changes in the sun's path is limited.

Through this theoretical framework, we will examine whether our local-first or global-first curricula provide a more productive pathway towards sophistication in students' scientific knowledge and whether the empirical results based on student learning support the organization of the overall seasons learning progression presented here.

Methodology

Participants and instructional context

A quasi-experimental design was used to compare the "local" curriculum to the "global" curriculum. Participants in this study were from students in the second author's 8th grade science classes. Students who returned parental consent forms and completed both pre and post instruction assessments were included in the study. Two classes (N=18) participated in the locally-focused curriculum while three classes (N=21) participated in the global-focused curriculum. Each class received ten days of instruction focusing on seasonal change. The students completed the same activities but in different orders ("local" first studied local seasonal changes and then studied global seasonal changes; for the "global" classes the sequence was switched). The curriculum was based on activities from The Real Reasons for Seasons (Gould, Willard, & Pompea, 2000), Project Star (Harvard Observatory, 2001), and teacher-created materials. Table 1 describes the order and topics covered in each condition.

Table 1 – Instructional Sequence for "local" and "global"-first curricula

Sequence	"Local"-first curriculum	Project 2061 "Global"-first curriculum
Day 1	• Review Day/Night, Earth's rotation • Shape of the Earth's orbit (LHS-GEMS) • Predictions on celestial hemispheres (Project Star)	• Review Day/Night, Earth's rotation • Shape of the Earth's orbit (LHS-GEMS)
Day 2	• Graph yearly temperatures in Maine • Graph yearly day length in Maine	• Graph yearly temperatures in Maine • Predictions on celestial hemispheres (Project Star)
Day 3	• Intensity of light in Maine (LHS-GEMS)	• Graph yearly temperatures for different locations (LHS-GEMS)
Day 4	• Daylight Hours in Maine (teacher materials)	• Graph yearly temperatures for different locations (LHS-GEMS)
Day 5	• Daylight Hours in Maine (teacher materials)	• Graph day length for different locations (LHS-GEMS)
Day 6	• Modeling Seasons in Maine (LHS-GEMS)	• Finish temperature and day length graphs
Day 7	• Graph yearly temperatures for different locations (LHS-GEMS)	• Intensity of light in Maine (LHS-GEMS)
Day 8	• Graph yearly temperatures for different locations (LHS-GEMS)	• Daylight Hours for different locations (teacher materials)

Day 9	• Graph day length for different locations (LHS-GEMS)	• Daylight Hours for different locations (teacher materials)
Day 10	• Finish temperature and day length graphs	• Modeling Seasons for different locations (LHS-GEMS)

Data Collection

All participants took the same written assessment before and after instruction. The assessment consisted of two multiple-choice questions written for this study, three multiple-choice questions drawn from The Real Reasons for the Seasons (Gould, Willard, & Pompea, 2000), and four open responses questions from Scale-Up project (Pyke, private communication). Questions were narrowed down to a short list of items (to avoid student fatigue in test-taking) assessing the central concepts that make up a full understanding of the seasons (Table 2). Distracters in the multiple-choice options as well as the seven open response questions allowed for identification of both common and unique misconceptions relating to the seasons. Open-ended questions allowed students to apply scientific reasoning to these questions. Table 2 describes the topics assessed and item design for each item (contact authors for additional information on assessment items).

Table 2 – Items used on pre- and post-instruction assessments

Item	Item type	Concept assessed and misconceptions addressed
1a.	Multiple choice	Shape of the earth (distracters include both oval orbits and off-centered sun postion)
1b.	Open-ended	Location of the earth in its orbit after one year
2.	Multiple choice	Stem prompts “the northern hemisphere is tilted away from the sun” with choices that vary the length of day and the altitude of the sun
3.	Multiple choice	Stem prompts “when the northern hemisphere is tilted towards the sun” with choices that compare the sun’s altitude in Northern US to Australia
4.	Multiple choice	Three drawings compare the size and distance between the sun, earth and moon.
5.	Multiple choice	Stem prompts “why is it hotter in our location in June than in December” followed by a list of accurate responses (sun is

		higher and days are longer in northern US location) and non-normative responses (e.g. distance from the sun, sun gives off more heat and light, etc.)
6a.	Open-ended	Image shows a pole's shadow and the sun's location at 9AM. Draw the location of a shadow cast by a pole at 3PM in the afternoon. Assesses knowledge of sun's apparent motion.
6b.	Open-ended	Explain why the shadow's location changed in the previous question (assessing understanding of earth's rotation to explain sun's apparent position).
6c.	Open-ended	Drawing shows a pole's shadow in summer and in winter. Explain why the sun appears higher in summer than winter. Assesses use of tilt to explain sun's apparent position.
7a.	Multiple choice	Item prompts students to choose whether the length of day in December will be more, the same, or less than in June for Buenos Aires.
7b.	Open-ended	Explain the previous item with knowledge of the earth (assessing relation between the length of day and the earth's tilt).
8a.	Open-ended	Explain the difference in temperature along the Atlantic coast at three locations in winter using understanding of light from the sun (assessing relationship between amount or intensity of sunlight and location on the earth).
8b.	Open-ended	Explain the difference between the average winter and summer temperature at the south Atlantic coast using light from the sun (assessing changes in amount or intensity of light over the course of the year).

Data analysis

Utilizing the BEAR (Berkley Evaluation and Assessment Research Center) Assessment System approach to analysis of student learning, we began by creating a 4-level construct map describing increasing proficiency of understanding the seasons (BEAR Center, 2009). A construct describes "part of a theoretical model of a person's cognition" (Wilson, 2005, p. 6). In this case, we are studying a construct map which describes increasing levels of sophistication of explaining the reason for the seasons. Student responses to both the multiple-choice items and the open-ended prompts were aligned to levels on the construct map through a scoring guide (BEAR System). The four-level scoring guide was defined as follows:

Score 1: Response does not resemble the scientific response.

Score 2: Response includes aspects of the scientific response but also contains non-normative ideas.

Score 3: Responses include aspects of the scientific concept but not the complete response (may be missing parts of an explanation) and does not include non-normative concepts.

Score 4: Response includes the complete scientific concept and does not include non-normative concepts.

Each answer option was assigned a score value for multiple choice questions. A coding scheme was developed to include all possible scientific and non-normative responses to the open-ended questions. These codes were then assigned score values. The first author coded all open-ended responses. The second author coded a sample of pre- and post-instruction data for 10 students (26% of the data). Inter-rater agreement for open-response items (7 out of 13 items) was 89% by codes and 94% by score (differences primarily arose through challenges in assignment codes to non-normative responses for scores 1 and 2).

Each student received an overall score on the assessment by summing their scores on individual items. An independent samples t-test was used to compare the pretest scores between the two conditions (Global and Local) to determine whether a significant difference exists between the two conditions. The results indicate that the students in the two conditions were drawn from the same population, based on their understanding of the seasons before instruction ($t = -.062$; $p = .951$).

The software *ConstructMap* (BEAR Center, 2009) allowed us to use item response modeling approach to describe students' proficiency levels in relation to the difficulty of items.

ConstructMap produces Wright Maps which allowed us to determine relative difficulties of items on our assessment and to compare person estimates against the levels of difficulty. We used this analysis to test our hypothetical learning progression for the seasons. First, the relative difficulties of items were used to create a potential order of concepts. Levels of the progression were ordered in response to difficulty of concepts according to the assessment. Second, the person estimate distributions on the Wright Map were analyzed for both pre-instruction and post-instruction to estimate how the instruction moved students along the proposed empirical-based learning progression. This was used to make suggestions for how future instruction could be designed to move students farther along the progression.

Findings

Comparing "local first" to "global first" on students' understanding of seasonal change

The results of a paired samples t-test indicates that there was significant improvement from the pretest to the posttest for the combined global and local conditions ($t = -7.458$; $p < 0.001$). We then moved on to examine whether or not the order of instruction made a difference in students' gains. An independent samples t-test was used to compare the posttest scores between the two conditions. No difference was found between the local and the global curriculum condition ($t=-.814$; $p=0.421$). From this, we may conclude that the order of study does not significantly impact the level of improvement.

We also attempted to look for differences between the two conditions by grouping items that tested understanding in different ways. First, we grouped the items that focused on a "global" understanding of the seasons (items 3, 7b, 8a) and for a "local" understanding of the seasons (items 2, 5, 6c, and 8b). An independent samples t-test was used to compare both the pretest (testing for pre-existing differences) and the posttest total (testing for differential improvement based on condition) for these questions. There was a significant difference found between groups for the pretest (t=--2.101; p<0.05) with the mean of the global condition (mean = 5.8, SD = 1.9) being higher than the local condition (mean = 4.7, SD = 1.4). There was no significant difference between the conditions for posttest on the "global" grouping of questions suggesting that instruction had a somewhat greater impact on the local-first condition students for this set of concepts. For the "local" understanding of the seasons questions, there was no significant difference between the local and global conditions for the pretest (t=0.205; p=0.839) or the (t=0.666; p=0.509).

Second, we grouped those questions that did not specifically connect to either the tilt explanation or changes in the sun's path as connected to changes in the seasons (items 1, 4, 6a, and 6b). There was no significant difference for the pretest (t=1.709; p=0.096) or for the posttest (t=1.197; p=.241). Students in both conditions showed the same relative improvement understanding of the earth's orbit, size-scale, and use of the earth's rotation. Third, a cluster of four items prompted students to demonstrate their understanding of the seasons in an open-ended written response. These items, which provided students the opportunity to offer alternative explanations, included: an item that asked them to explain why the sun is higher in summer compared to winter in their own words (6c), an item comparing the length of day in Buenos Aires in December and June (7b), and items comparing differences in temperatures locations along the Atlantic coast and in different seasons (8a and 8b). These questions tested whether students understood both how the earth's tilt affects the length of day and altitude of the sun as well as their ability to explain the affect of the earth's shape and the observer's location to differences in the sun's intensity and changes in temperature. We used an independent samples t-test to compare both the pretest and the posttest total for these questions. There was no significance found between groups for the pretest (t=-0.682; p=.500) or for the posttest (t=1.106; p=.276). Differences in instruction did not result in differential improvement for questions about the seasons that required written justification.

Comparing student improvement in understanding of seasonal change to item difficulty

A Wright Map was produced to compare student proficiencies against item difficulty with the overall goal of using this to revise our hypothetical learning progression. In this way, we were able to examine the relative difficulty of the assessment items and potentially the underlying conceptual challenges that prevent students from achieving the scientific level of response. A Wright Map showing all students, with pre in the first column and post in the second column is found in Figure 1. In the third column (item numbers on the far right), the Thurstonian thresholds are indicated for each item level (items were modeled using pre- and post-instruction data for all 39 students as if they were 78 separate people). A Thurstonian threshold is "the location at which students have a 50% probability of achieving that score or higher" (BEAR Center, 2009). For example, item 6b has a Thurstonian threshold of 1.0 for step 3 (step 3 refers to a score of 4 on the assessment coding). Respondents with a proficiency of 1.0 logits are as likely to score 1, 2, or 3 for item 6b as they are for achieving Score 4. In Figure 1 only one student has a proficiency of 1.0 logits. The remaining students have lower proficiencies, meaning that they have less than a 50% probability of achieving step 3 (a score of 4 on the assessment). Reading from top to bottom in the Thurstonian threshold column shows the item difficulty from most to least difficult. Thus achieving a score of 4 on items 8a and 8b are the most difficult and achieving the accurate score (Score 4) for item 3 is the least difficult for students to achieve. The Wright Map allows us to determine relative difficulties of items on our assessment and to compare students' proficiency against the levels of difficulty.

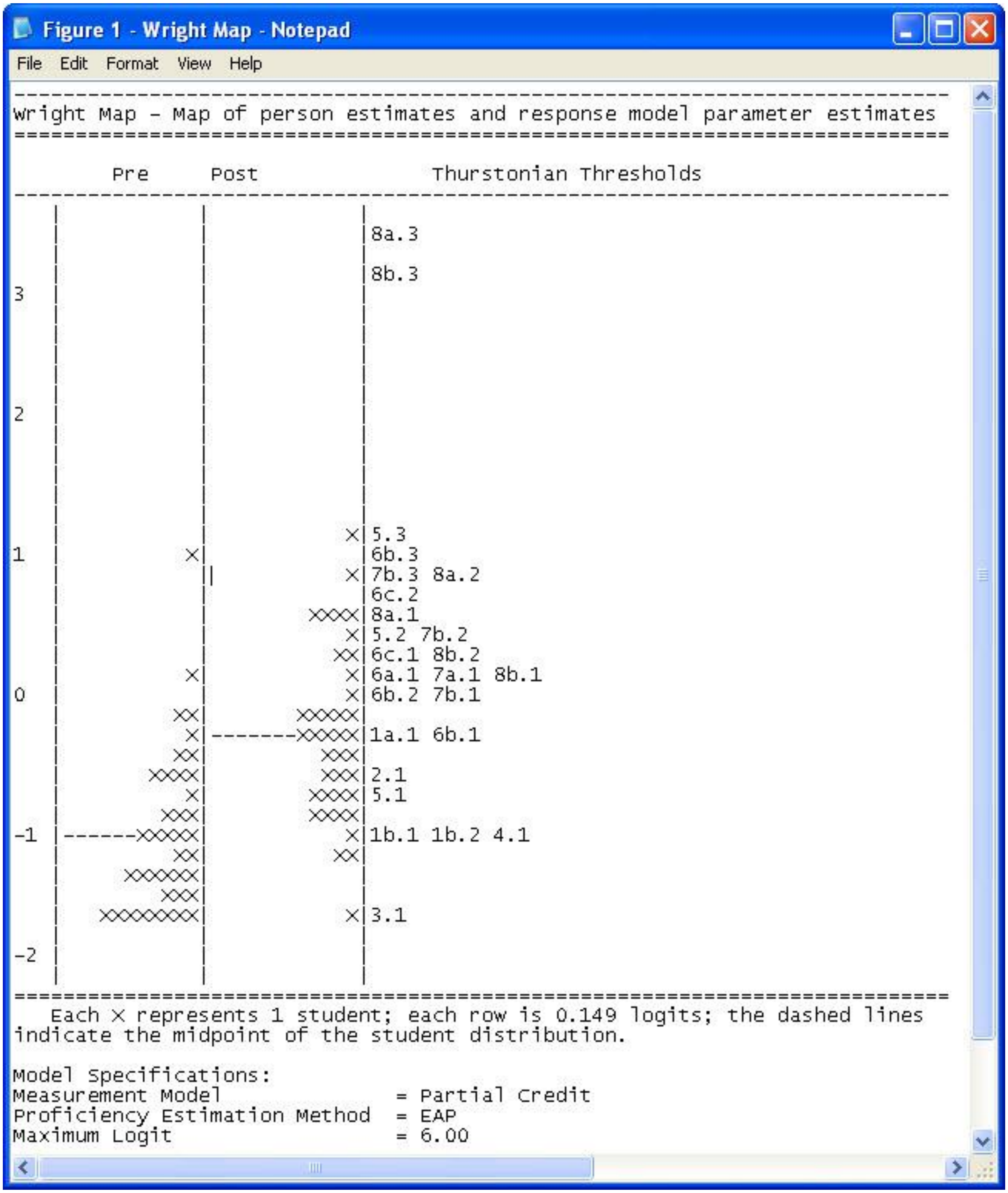
Figure 1 - Wright Map - Notepad

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------------------------------------------------------------------------------
Wright Map - Map of person estimates and response model parameter estimates
==============================================================================

        Pre      Post              Thurstonian Thresholds
------------------------------------------------------------------------------
   |           |            |
   |           |            |8a.3
   |           |            |
   |           |            |8b.3
3  |           |            |
   |           |            |
   |           |            |
   |           |            |
   |           |            |
   |           |            |
2  |           |            |
   |           |            |
   |           |            |
   |           |            |
   |           |            |
   |           |           X|5.3
1  |          X|            |6b.3
   |           ||          X|7b.3 8a.2
   |           |            |6c.2
   |           |        XXXX|8a.1
   |           |           X|5.2 7b.2
   |           |          XX|6c.1 8b.2
   |          X|           X|6a.1 7a.1 8b.1
0  |           |           X|6b.2 7b.1
   |         XX|       XXXXX|
   |          X|-------XXXXX|1a.1 6b.1
   |         XX|         XXX|
   |       XXXX|         XXX|2.1
   |          X|        XXXX|5.1
   |        XXX|        XXXX|
-1 |------XXXXX|           X|1b.1 1b.2 4.1
   |         XX|          XX|
   |     XXXXXX|            |
   |        XXX|            |
   |   XXXXXXXX|           X|3.1
   |           |            |
-2 |           |            |
   |           |            |
==============================================================================
   Each X represents 1 student; each row is 0.149 logits; the dashed lines
indicate the midpoint of the student distribution.

Model Specifications:
Measurement Model                   = Partial Credit
Proficiency Estimation Method       = EAP
Maximum Logit                       = 6.00
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Item difficulty is influenced by two factors: a) the authors' decisions, based on scientific reasoning, about the ordering of accuracy of the items (e.g. a scientifically accurate response was scored higher than a similarly scientific response that <u>also</u> contained misconceptions) and b) students' cognitive development in relation to these topics. We analyzed the ordering of item scores with respect to their Thurstonian thresholds to find patterns in the difficulty of learning concepts related to the seasons. Based on this analysis, Table 3 lists concepts (based on group items of similar Thurstonian thresholds) from most difficult to least difficult. This is not a strict restating of the items because some items are listed more than once and in most cases multiple items are grouped based on their location on the Wright Map. Some items have multiple levels of accuracy (the scoring guide).

Table 3 – Interpretation of Item Difficulty for Development of Seasonal Change Concepts

Concept groupings based in item difficulty, listed from most difficult to least difficult	**Evidence from Wright Map**
Seasonal change in temperature is caused by both a change in the sun's altitude and the length of day and these are explained by the earth's tilt. No other inaccurate explanations or descriptions are included in responses.	Items placing at this level of the Wright Map do not include any inaccuracies (6c.2, 8a.2, 7b.3, 6b.3, 5.3, 8b.3, and 8a.3); though at the lower section of this group responses may not include all three pieces.
The length of day or altitude of the sun, and the tilt of the earth, are involved in explaining seasonal temperature change on the earth and students recognizes these items as explanatory factors relating to the changes in regional temperature but retain other inaccuracies and/or incomplete explanations.	Students are able to use the earth's tilt to explain seasonal changes in shadows but continue to have additional inaccuracies in their understanding (6c.1). Items that inform this category are 8b.2, 6c.1, 7b.2, 5.2, and 8a.1 (from lower to higher Thurstonian thresholds). The order of the levels suggests that these are complex ideas and that an interaction between the item complexity and students' knowledge is responsible for the pattern seen in the data.
Knowledge that the southern hemisphere will get more sunlight in December while the northern hemisphere gets less and vice versa, but inaccuracies or limitations remains in the explanations.	Items 7a.1 and 7b.1 test for this knowledge in a more complex setting than item 3. These items placement with respect to the Thurstonian thresholds of other items suggests that because of the complexity of the scenario, this item may be a more reliable measure of integrated understanding than item 3. [This item is marginally lower than the next level, above.]
The earth's rotation causes the sun's apparent motion.	Students who reached Level 3 and 4 of item 6b accurately used the earth's rotation without any other mediating, non-normative, factors.

The earth's orbit appears circular and the earth's rotation is involved in the apparent motion of the sun.	Items 1a.1 and 6b.1 fall closely together on the Wright Map, above the previous levels. Students achieving this level of understanding may still include other alternative ideas in their explanation for the sun's apparent motion.
The length of day and altitude of the sun are important to explaining the seasons but are not necessarily integrated with descriptions of the sun's path and the tilt of the earth.	Placement of items which distinguish the knowledge of these concepts from lack of knowledge low on the Wright Map (items 5.1, 2.1, and possible 3.1). These items allow for alternative conceptions or do not test for alternative conceptions.
Knowledge of earth's orbit and the scale of the sun-moon-earth system.	Placement of items 1b.1 and 4.1 low in the Wright Map scale.

An Empirically-Supported Learning Progression for Seasonal Change

The analysis of the item difficulty from the Wright Map allows us to re-organize our hypothetical learning progression based on the empirical data presented above. In this section, we will present each level of the revised learning progression for seasonal change, from least sophisticated to most scientific, describe how students from this study changed from before to after instruction, and discuss the implications of these levels for instruction that moves students from a lower to a higher level of sophistication. When appropriate, we draw on existing literature to support our claims for the description and order of these levels or instructional designs that impact student positions relative to the learning progression.

Naïve View of Seasonal Change

As in any learning progression, the first level describes where students enter the learning progression, typically as early elementary students without significant instruction on the topics. However, they do have their own experiences with the world to build on. As expected, at this level, students do not use the earth's tilt to explain seasonal change. But more than this, students do not know about the apparent change in the sun's path across the seasons. Studies of elementary and middle school students (Plummer, 2009a) as well as adults (Mant & Summers, 1993; Plummer, Zahm, & Rice, in press) demonstrate that learners are often unaware of the changes to the sun’s apparent path between summer and winter, including the change in the sun’s altitude.

Based on our assessment and analysis of item difficulty on the Wright Map, students may have knowledge of some fundamental astronomical concepts such as the idea that the earth orbits the sun once a year (prior to instruction 62% of students could use a drawing to show the earth’s returns to the same spot every year) and the relative size-scale of the sun-earth-moon system (prior to instruction 46% of students) at this naïve level. These concepts are relatively easy compared topics that change over time, those that ask students to compare locations or to explain observable evidence. In fact, prior to instruction, the midpoint of the person estimate on the Wright Map falls at the response model parameter for these items; most of the students are likely to fall in this naïve level of understanding. This seems to be the likely placement of most elementary and middle school students before instruction on the seasons.

Observational Knowledge – Disconnected from Scientific Explanatory Model

Students who move into this level can now recognize that changes in the sun’s altitude and the length of day across the seasons are important for explaining the seasons. At this level, students know that these changes are in relation to the earth’s tilt but are not yet able to provide their own explanations of observable changes with an accurate use of the tilt-model; they are likely to still use non-normative explanations for the seasons or to have an inaccurate understanding of the earth’s tilt. Students are accommodating new concepts that conform to the scientific norm, concepts emphasized through schooling, but not abandoning or changing previous conceptual models. Many students at this level cannot use the earth’s rotation to explain why sun to appear to move across the sky and believe that the earth moves closer and farther away from the sun (these concepts are discussed in the next section). Recognition of the association of the word “tilt” with changes in the sun’s altitude and length of day (the items which defined this level were all multiple choice and did not provide opportunity to express non-normative explanatory models) indicates only an initial familiarity with the scientific concepts, not a depth of understanding.

Prior to instruction, analysis of the Wright Map indicates that the majority of students (72%) had less than a 50% chance of answering these questions correctly and much less than 50% chance of answering questions accurately that would move them into the next more sophisticated level of the learning progression. Overall, the level of seasonal knowledge of these students was very low before instruction indicating that the majority of students fell below this level of sophistication. Prior to instruction, 72% of students knew that when the northern hemisphere is tilted towards the sun, that the sun is high in their northern location and low in the sky in Australia (based on a multiple choice question). However, only 44% of students knew that when the northern hemisphere is tilted away from the sun that the sun is lower in the sky and the days are shorter. And only 49% of students could, at the minimum, state that either the length of day or the altitude of the sun cause the earth to be warmer in their location in summer (all but 10% also choose inaccurate explanations, such as changing distance from the sun). These results suggest that students are aware of a difference in the seasons between the hemispheres and may be more aware of differences in altitude between the seasons than the length of day. But they may not necessarily connect those observations with changes in temperature.

Instruction that moves students into this level helps students recognize changes caused by the sun’s changing path over the course of the year. For example, students in this study compared changes in seasonal temperature change to seasonal changes in length of day through graphing activities. They also investigated changing intensities of light at their local. After instruction, most students (62%) had a 50% probability or greater of answering items in this level accurately, showing an improvement along the learning progression. Addressing the three items that helped us define this level, 85% of students knew that when the northern hemisphere is tilted towards the sun, that the sun is high in their northern location and low in the sky in Australia (based on a multiple choice question). Seventy-four percent of students knew that when the northern hemisphere is tilted away from the sun that the sun is lower in the sky and the days are shorter. And 82% of students could state that either the length of day or the altitude of the sun cause the earth to be warmer in their location in summer (though 54% of all students continued to select inaccurate responses so many of these students combined scientific and non-scientific responses).

Celestial Motion – Prerequisite Knowledge for Understanding of the Seasons

Why are these concepts necessary for advancement to increasingly sophisticated understanding of seasonal change? From a logical perspective, deconstructing the idea of the tilt-model, the earth's rotation is required to understand why the altitude of the sun and the length of day changes over the seasons. Students are not able to successfully and accurately integrate these observational concepts within their current explanatory model without a sophisticated understanding of the earth's daily rotation motion combined with an ability to shift frames of reference to understand what we experience from the earth's surface.

To advance their understanding of seasonal change, students need to understand that the earth's rotation causes the sun to rise and set and the earth's orbit appears circular. This level, while not directly addressing the explanation for the seasons, describes a level of understanding that is prerequisite for advancing to more sophisticated concepts. This assumption is also supported by the Wright Map analysis; use of the earth's rotation to explain apparent motion of the sun and the shape of the earth's orbit appear more difficult than previously described concepts and less difficult than concepts which begin to integrate the tilt model with observable changes to the sun's path. Further, prior to instruction only 38% could accurately indicate the change in the sun's position across a single day (apparent daily motion of the sun), 36% of students could explain the sun's apparent daily motion with the earth's rotation (without including other inaccurate explanations) and 36% could identify the correct shape of the earth's orbit (a circle with the sun located at the center, not to the side, and not an oval shaped orbit). However, in this study, these are concepts that most standards documents indicates students should learn in upper elementary school (Palen & Proctor, 2006) and were thus not the focus of instruction. After instruction, 41% of the students accurately described the change in the sun's shadow, 56% explained this motion with the rotation of the earth, and 72% correctly identified the shape of earth's orbit.

Prior research has shown that without instruction, many children and adults will not acquire this level of sophistication in their understanding of the earth's rotation (Plummer & Slagle, 2009a, 2009b; Plummer, Zahm, & Rice, in press). The level of sophistication required to explain the seasons goes beyond just knowing that the earth rotates. Many children can state that the earth rotates once per day but do not use that concept to explain their observations of the sun's apparent motion (Plummer & Slagle, 2009a, 2009b). Prior to instruction, children may hold a naïve concept that the sun appears to go up and down each day because it is actually going up and down. As students encounter scientific concepts, they may reorganize their thinking to believe that the sun rises and sets across the sky because the sun is circling around the earth or that the earth is circling around the sun (Vosniadou & Brewer, 1994). In a study of third grade students, 13% (N=24) accurately used the earth's rotation to explain the sun's motion before instruction (Plummer & Slagle, 2009b). After traditional instruction, this only increased to 33% of the students. In a study of pre-service elementary teachers using similar assessment methods, only 61% (N=18) accurately used the earth's rotation to explain the sun's apparent daily path before instruction (Plummer, Zahm, & Rice, in press).

Extensive research has shown that students often believe that the seasons are caused by the earth getting closer and farther from the sun (e.g. Baxter, 1989, Sharp, 1996, Trumper, 2001). Some have claimed that this may be influenced by misleading or inaccurate diagrams in textbooks that show a highly elliptical path of the earth's orbit. Such an orbit would appear to confirm the naïve explanation. Students who have moved to this level have learned that the shape of the earth is nearly circular. Holding such a concept may help, with a focus on how to use the tilt model, move students to a sophisticated scientific perspective. Instruction that can help move students towards this conceptualization of the earth's orbit include activities that emphasize the very small changes in the earth's orbit and that (for northern hemisphere observers) we are closest to the sun in winter months (Real Reasons for the Seasons). This will not, however, prevent conflict with students' alternative explanation that the earth's tilt moves our part of the earth farther away and closer to the sun.

Global Observational Knowledge

Students at this level have adopted the prior levels of knowledge and can describe differences in sunlight between the northern and southern hemisphere in complex situations. Prior to these level students may know the change between hemispheres but as factual items rather than an integrated understanding that relates to the shape of the earth and complex situations. Two items seemed to test this concept. One item was a simple multiple choice item based on the sun's altitude that did not provide an opportunity for students to express misconceptions. The other item was an open-response item that asked students to compare the amount of light received between Buenos Aries and the students' home location in the northern hemisphere. This item required students to express more complex ideas and support these in writing. The second item's difficulty level on the Wright Map resulted in the placement of this concept at this point in the learning progression because for students to adopt a full and integrated understanding of how one's location on the earth impacts the amount of sun we receive may require understanding of celestial motion described in the previous level.

Synthetic Global Explanations

At the synthetic global level, students have assimilated aspects of the scientific model but either retain other non-normative explanations or leave out key pieces of the scientific explanation (Vosniadou & Brewer, 1992, 1994). To reach this level of sophistication, students are able to compare temperatures across latitudes in the same hemisphere and length of day or intensity of sunlight in their comparison. They can also compare the amount of sunlight across the northern and southern hemisphere and how this will change across the seasons. They are likely to use intensity of light or the change in length of day to explain why temperature in a given location changes. They are also familiar enough with the earth's tilt to use it to explain why a shadow cast by the sun changes seasonally. But they cannot use the earth's tilt to provide a completely scientific explanation of the shadow phenomenon or more global seasonal changes. They have inaccuracies or omissions in their explanations for seasonal change. The Wright Map indicates that, prior to instruction, only two students had a 50% or greater probability of responding correctly to items at this level. After instruction, slightly more students (26%) had reached a 50% probability or greater of responding correctly to these questions.

To move into this level, students have had experiences with observational data and the explanatory tilt model. But they are not proficient at the use of these concepts and models or they have not experienced these concepts in enough depth to abandon their previously held ideas. To move to the next level of accuracy, these students will need additional experiences using the tilt model to explain observations.

Scientific Explanation of the Seasons

In the highest level of sophistication of our learning progression, students are aware that both the altitude of the sun (which impacts the intensity of sunlight) and the length of day cause the seasons. They use the earth's tilt to accurately explain these apparent changes that affect our planet. And they are able to make accurate comparisons between the northern hemisphere and the southern hemisphere, using both observational and explanatory descriptions. This level was assessed in our analysis by four open ended questions addressing seasonal change across hemispheres, across latitudes in the northern hemisphere, and between seasons, and a multiple choice question that provided students the opportunity to choose both accurate responses and several often-held alternative ideas. This level also included an item that asked students to explain the changing appearance of a shadow at noon (accurate responses use the earth's tilt to explain this observational data). Prior to instruction, one student had a 50% probability of reaching this level of sophistication. After instruction, only two students were placed at the 50% probability level on the Wright Map.

Discussion and Conclusions

This study takes a first-step into the development of a learning progression that culminates with a sophisticated knowledge of the explanation for the seasons. We began by proposing a hypothetical learning progression that described a possible pathway that students may take to progress towards scientific understanding of the seasons. This hypothetical learning progression was partially based on the prediction that students who contextualize their understanding of the seasons through their own local conditions will make greater gains in their understanding than those who begin with the de-contextualized global perspective. Our local versus global hypothesis was not supported; no statistical differences were found between the two groups. Using the statistical analysis software, *ConstructMap*, we then examined complexities in students' difficulty with concepts related to the seasons. Using this data, we revised our hypothetical learning progression to propose an empirically-supported learning progression for the seasons.

The first major conclusion from our study is to draw attention to the importance of fundamental knowledge in astronomy as prerequisite to advancing in sophistication on the seasons learning progression. Students who lack a sophisticated understanding of the relationship between the earth's rotation and our observations of the sun and the shape of the earth's orbit may find that the more sophisticated concepts which use tilt and the angle of the sun's rays to be incompatible with or incomprehensible to their mental model. Developing students' knowledge at the lower rungs of the learning progression should hypothetically be the function of elementary school astronomy instruction. On average, state standards suggest that the seasons be covered in the 6th grade (Palen & Proctor, 2006) while the Atlas suggest that full understanding of the tilt model and the seasons be placed at the 9-12 grade range. We do not argue that these results suggest the importance of the actual grade level that students should learn the seasons. Rather, we point to the complexity of the seasons as a set of observations combined with an explanatory model and support the need for creating learning progressions that help teachers and curriculum developers' work towards building concepts over time through more sophisticated levels of understanding. Our findings support the need for students to have a fully developed understanding of the connection between the earth's rotation and the sun's daily path across the sky and the nature of the earth's orbit. Both logically, and based on our data, this would appear to be a large stumbling block towards progress in understanding the seasons.

Our data also supports the proposed order of instruction from *Benchmarks*. Specifically, *Benchmarks* suggests that students first become familiar with observable patterns of change in the sun's intensity and length of day as well as relating those changes to seasonal temperature changes before addressing these changes using the tilt model of the earth. While students may suggest the "tilt" as the reason for the seasons or the reason for global observable patterns (sunlight or temperature), for many this is a parroting of scientific language rather than the application of a complex celestial motion model that requires the ability to understand changes to the earth from multiple frames of reference. Focusing first on students' development from a learning progression standpoint would allow them to progress in sophistication rather than surface level facts.

Learning progression-based research that draws on the existing literature base has implications for designing educative curriculum. Educative curricula support teacher learning in a variety of ways including anticipating and addressing students' ideas about scientific phenomena (Davis & Krajcik, 2005). The existing literature identifies several alternative explanations for the seasons. Curriculum design should provide teachers with a) instructional guides that structure concepts appropriately based on students' prior knowledge, b) strategies that allow students to compare known common alterative ideas with the appropriate scientific concepts, and c) support in scaffolding students in moving between observable patterns of the sun's apparent motion and the underlying tilt-model. One step towards providing educative curriculum elements with regards to the seasons could emphasize the importance of pre-instructional and formative assessments used to diagnose students' placement along the learning progression. Middle school and high school teachers may not recognize the limited knowledge held by their students with regards to the earth's rotation and orbital motions or the difficulty students have in acquiring these concepts. Such pre-instruction and formative assessment should include:

- The change in the sun's apparent motion across the seasons (Plummer & Krajcik, 2010). This should include how the sun's altitude changes and the length of day. Assessment should also consider whether students recognize the connection between these observations and temperature patterns.
- How the earth's rotation explains the sun's apparent motion. The simple knowledge that the earth rotates does not necessarily indicate that the student can use that concept to explain observations (Plummer & Slagle, 2009b).
- The shape of the earth's orbit.

Assessment along these points would help teachers recognize where they should begin instruction that would progress students towards the tilt model of the seasons. Beginning with the tilt model, or even global sunlight and temperature patterns, are likely to be unproductive for students beginning at a naïve view of astronomical concepts.

Our hypothesis, that first learning about the seasons from a local, contextualized, perspective followed by activities relating to a global-perspective would result in great improvement in understanding compared to the global-first curriculum, was not supported by the data. Because there was no difference in the magnitude of improvement between conditions, we conclude that, given a similar application of season-related activities, curriculum can be designed in either order. Students were able to construct understanding of the seasons in a similar pattern regardless of the order of topics. However, two important caveats should be considered. First, the students' movement along the learning progression did not, for most students, reach the scientific end of the progression. Students' starting point on the progression (primarily naïve seasonal knowledge) may have limited the effectiveness of a local- versus global-perspective. Second, we may consider the idea of contextualization in another light. Rather than considering the importance of the local geographic experience, perhaps we should consider the contextualization to be based on patterns of data that are observable and relatable to everyday life. This would include the change in the sun's altitude, the change in length of day and the seasonal temperature changes. Beginning with these concepts as the focus may be the contextualization necessary to then introduce the unfamiliar and unobservable: the tilt model of the earth.

Another way that our findings contribute to the growing field of learning progression development is to highlight the testing of standards-based hypotheses. Standards documents, such as *Benchmarks*, suggest sequences of topics and even make connections between these topics as proposed learning trajectories. Our study supports an often overlooked aspect of learning progression research: "A learning progression proposes and clarifies one (or more) possible paths and does not represent a complete list of all possible paths (Corcoran et al., 2009)." While additional work needs to be done to assess the progress of students understanding within the instructional sequence towards learning the scientific explanation for the seasons, we can support the notion that different orders in which concepts are learned about the seasons (as described above) may result in similar learning patterns and suggest that similar research is beneficial to progress in learning progression research.

One of the major challenges in teaching students about the seasons is the limited amount of time dedicated to astronomy in schools. It is unclear how much time, on average, is spent on science in elementary school but anecdotal evidence suggests that this has been cut or severely limited in schools in recent years. Astronomy receives small attention, if any. At the secondary level, astronomy has been relegated to an elective status at the high school level (Krumenaker, 2009). Some districts do not require any astronomy to be taught at the middle or high school level (Plummer & Zahm, in review). This is then combined with the complexities of achieving a scientific level of understanding of the concept – combining shifting frames of reference with understanding of light, energy, and change over time. One of the arguments for learning progression-based research is to help policy makers make decisions on how to focus our standards documents on those core ideas that will be beneficial across a larger body of scientific knowledge. Part of this must address those concepts that are broadly useful and those for which mastery is a challenge. Clearly, the conceptual understanding required for seasons is of significant difficulty, given the prevalence and persistence of non-normative explanations among children and adults. Based on this, we argue that if instruction at the middle school level is undertaken with the goal of explaining the seasons then significant time must dedicated to developing the concept. This is especially true given that many students are likely to enter middle school with poorly developed understanding of the earth's rotation and orbit. Further research is needed to understand how findings such as these can be used to influence state-wide and district-level instructional decisions in science.

The work presented here is preliminary in three major respects: 1) additional analysis remains with the existing data set to analyze outcomes by categorizing each student according to the proposed learning progression; 2) stronger connections will be developed between this study and our previous learning progression research in celestial motion (Plummer & Krajcik, 2010; Plummer & Slagle, 2009a, 2009b); and 3) existing literature will be examined to provide additional depth in our discussion of the instructional strategies that move students along the progression towards increasing sophistication. Beyond our own work on this study, additional research that explores seasons-related instruction should address the upper levels of the learning progression to better explore the relationship between student experiences and complex cognitive processes involved in explaining the seasons.

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