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Identifying A Baseline for Teachers' Astronomy Content Knowledge

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Abstract

A teacher's scientific understanding has a dramatic impact on students' ability to learn science. This article describes the results of administering the Astronomy Diagnostic Test to 142 science teachers in Wisconsin. The results show that these teachers are lacking a deep, coherent understanding of astronomy concepts. Implications for these results on professional development of in-service educators are suggested.

1. INTRODUCTION

Research has indicated that teacher quality is an important factor in increasing student achievement (Greenwald, Hedges, & Laine 1996). Superficial content understanding leads teachers to emphasize memorization of isolated facts and limits their ability to teach in a creative and innovative manner, making them afraid to introduce lessons that may encourage students to move beyond the teacher's knowledge (Gess-Newsome 2001). Lower-level questioning and cookbook activities dominate the instructional practices of teachers with limited content knowledge. These teachers also limit the use of student questions in classroom discourse and the development of conceptual connections, and often misrepresent the nature of the discipline.

Many assume that teachers know the "stuff" that they are supposed to teach (Mosenthal & Ball 1992). However, teacher understanding of the content that they are teaching should not be taken for granted. During the 1999-2000 school year, only 55% of high school students received physical science instruction (chemistry, earth science, and physics) from a teacher with a major or minor in physical sciences. At the middle school level, only 18% of students received physical science instruction from a teacher with a major or minor in physical sciences. Nearly 50% of middle school students received physical science instruction from a teacher without a major or minor in any science or science education field (National Science Board 2004).

The purpose of this study is to characterize the astronomy content knowledge of in-service teachers. Specifically, the study intends to answer this question: What is the baseline astronomy knowledge of elementary and secondary teachers? An understanding of the current baseline of teacher content knowledge in astronomy will be valuable to designers of professional development programs. This study confines itself to investigating the content knowledge of teachers in Wisconsin. Additionally, the sampling-by-convenience procedure used in this study may limit the generalizeability of the study to a national population.

2. REVIEW OF LITERATURE

Adams & Slater (2000) described the progression of astronomy concepts as found in the National Science Education Standards (1996). The astronomy-related standards for elementary grades include two related to identifying the properties, locations, and movement patterns for objects in the sky. Slater and Adams explained that students should learn about these patterns from a geocentric perspective based on observations. The third astronomy standard at the elementary level involves understanding that the Sun is the principal source of energy for the Earth. At the middle school level, students should begin learning about the movement of Solar System objects from a heliocentric perspective. This includes understanding the cause of the seasons and phases of the Moon. Middle school students should also gain an appreciation for the effect of gravity on the Earth and within the Solar System, and know that the Sun is a star that provides energy for the Earth. At the high school level, students should understand current scientific theories related to the creation of the Universe, the Solar System, and atoms. High school students should understand processes related to galaxies and stars, including an understanding of the nuclear fusion process that powers stars. Reviews of astronomy education research literature by Adams & Slater (2000) and Bailey & Slater (2003) show that substantial research related to student understanding of the causes of the seasons and phases of the Moon has been conducted, but only initial studies have been conducted to describe student learning of patterns from a geocentric perspective and more complex astronomy concepts included in the high school National Science Education Standards.

For students to learn and understand the concepts described in the National Science Education Standards, it is fundamentally important that these students’ teachers have a strong understanding of astronomy concepts and how best to present these concepts to their students in an age-appropriate manner. In their review of astronomy education research, Bailey & Slater (2003) concluded that there is little connection between the research that has been performed and its effect on classroom instruction. Additionally, they noticed a gap in research pertaining to teacher understanding of astronomy and effective methods for preparing astronomy teachers at all levels. They stated, "Very little work has been done in this area, although it is still seen by many as one of the highest and most timely priorities in the field."

Atwood & Atwood (1996) studied preservice teachers’ understanding of the seasons. Trundle, Atwood, & Christopher (2002) studied preservice elementary teachers’ understanding of the phases of the Moon. Both of these studies showed that many of the participants exhibited misconceptions related to these topics. Slater, Safko, & Carpenter (1999) developed a constructivist-based astronomy course for in-service elementary and middle school teachers. Their preassessment found that teachers often avoid astronomy topics because of their lack of confidence and a lack of quality resources. After instruction, the confidence level, content knowledge, and ability to teach the content had increased. Evidence that these increases were maintained was found during a follow-up survey four years after the course. Although these studies provide some insight into the content knowledge of teachers, no research was found that looked at teacher knowledge of astronomy across grade levels and multiple astronomy concepts.

3. METHODOLOGY

To determine the baseline content knowledge of precollege teachers, the Astronomy Diagnostic Test was given to participating teachers during a series of weeklong space science workshops conducted by Space Education Initiatives. These workshops were part of the Wisconsin Academies for Staff Development Initiative conducted in the summer of 2002. The ADT was administered during the first morning of instruction, so the results are a measurement of the participants' incoming astronomy knowledge.

The Astronomy Diagnostic Test (ADT) is a multiple-choice test that uses everyday language to determine the conceptual understanding of common astronomy topics. The ADT evolved from an astronomy misconceptions measurement instrument designed as part of a grant-supported reform effort for introductory astronomy courses at the University of New Mexico (Zeilik 2003). The development of this early version of the ADT began by having a panel of 19 introductory astronomy instructors rank the most essential concepts for introductory astronomy courses. Questions on this early version of the ADT were culled from the astronomy education research literature and refined through undergraduate student focus groups over four semesters. The Astronomy Diagnostic Test version 2.0 expanded and refined this initial test by including questions from the Project STAR Astronomy Concept Inventory and rewriting questions to avoid scientific jargon and to measure only one concept per question. The test designers also ensured that the concept tested was included in the National Science Education Standards (Hufnagel 2002). Hufnagel described how the reliability of the test was determined by using three approaches: (1) statistical analysis of hundreds of students taking the ADT across the United States; (2) written responses from 30 students who received the ADT questions but not the distractors; and (3) 60 interviews of students enrolled in introductory astronomy courses at the University of Maryland and Montana State University.

In the current study, the ADT was completed by 142 classroom teachers, including 43 elementary teachers (grades K-4), 73 middle school teachers (grades 5-8), and 26 high school teachers (9-12) from Wisconsin. The participants represent the geographic diversity of the state. Demographic data related to gender and ethnicity were not collected. The results of the ADT and analysis of the results are described in the following sections.

4. RESULTS

The Astronomy Diagnostic Test (version 2.0) contains 21 multiple-choice items that gauge the understanding of a variety of astronomy concepts. Test results from the 142 participants are grouped by grade level. Elementary teachers had a mean score of 35% (*SD* = 13), middle school teachers had a mean score of 50% (*SD* = 16), and high school teachers had a mean score of 64% (*SD* = 12). Table 1 summarizes responses to individual test items.

Table 1. Responses to Individual Items on ADT 2.0

Item	**% Correct (K-4)**	**% Correct (5-8)**	**% Correct (9-12)**

1. Position of the Sun in the sky and shadows	39	41	56
2. Eclipse and Moon phase	26	43	47
3. Earth / Moon scale	18	33	32
4. Gravity	61	85	95
5 Electromagnetic radiation	14	23	50
6. Gravity and "weightlessness" in orbit	8	42	37
7. Seasons and Earth’s orbit	28	50	58
8. Origin of Sun’s energy	17	46	56
9. Change in the position of the Sun in the sky over time	46	57	95
10. Position of the Sun and constellations in the sky	27	23	32
11. Earth / Moon / space shuttle scale	42	73	68
12. Earth / Solar System / stars scale	30	65	74
13. Object arrangement by distance	39	59	79
14. Gravity	30	45	84
15. Light and inverse square relationship	19	24	63
16. Location of the center of the Universe	63	67	74
17. Star color and temperature	43	52	75
18. Moon phases	25	53	63
19. Moon phases and Moon motion in the sky	77	85	95
20. Angular distance	54	44	63
21. Cause of global warming	22	45	56

5. DISCUSSION

The Astronomy Diagnostic Test National Project investigated the astronomy knowledge of undergraduate students in introductory college astronomy courses. The ADT national sample included more than 5,000 pretests and more than 3,000 posttests from 97 courses (Demming 2002) between 1999 and 2001. The mean pretest score was 32.4% (*SE* = 0.21%), and the mean posttest score was 47.3% (*SE* = 0.32%). Elementary teachers in Wisconsin scored slightly higher on the ADT than the average pretest score in introductory college astronomy. Wisconsin secondary science teachers scored higher than the posttest scores in introductory college astronomy. However, the mean score for each group of Wisconsin teachers participating in the current study was less than the mean score of non–science majors taking advanced astronomy undergraduate courses (*M* = 66%; Hufnagel 2002).

Items on the ADT measure discreet astronomy topics and contain distractors that can be used to identify alternate conceptions. Therefore, analysis of individual test items is more useful than looking at a composite score. Items on the ADT can be divided into four distinct conceptual categories. The Sense of Scale category contains five questions related to size and distance of celestial objects. The Motion category contains seven questions related to planetary motion, phases of the Moon, seasons, and other phenomena that relate to motion. The Gravity category contains three questions related specifically to gravity. The General category contains six questions, including physical science concepts related to astronomy and other astronomy concepts not described by the other categories.

5.1 Sense of Scale

This category contains questions 3, 11, 12, 13, and 20. Question 3 addresses the relative distance between the Earth and the Moon. The average score on this item was 26%. For each group, the most common response was only 1/10 of the actual scale distance between the two objects. Question 11 asked about the relative distance between the space shuttle and Earth compared with the Moon and Earth. The average score for this question was 60%. Interestingly, middle school teachers scored higher than high school teachers on this item. The most common wrong answer for each group was that the space shuttle flies about halfway to the Moon. Question 12 is used to identify conceptions of scale beyond the Solar System by asking how far from the Earth you would have to be in order for the pattern of the Big Dipper to look different. Slightly over 50% of all participants answered correctly that you would have to be at a distant star. The most common wrong answer was that you would need to view the Big Dipper from Pluto. In question 13, teachers have to correctly order objects based on their distance from the Earth. Only 53% of participants answered this correctly. Nearly 80% of high school teachers and 59% of middle school teachers answered this correctly, while less than 40% of elementary teachers answered correctly. It is likely that many of the incorrect responses were a result of misreading the question, because the most common incorrect answer placed Pluto closer to the Sun than the Earth. However, 20% of the teachers answered that "stars" are closer to the Earth than Pluto. Question 20 is used to identify understanding of angular size by asking what size an object would need to be to "cover" the Sun on Saturn if your thumb could cover the Sun while on Earth. Just over 50% of participants answered this question correctly, with the most common wrong answer being an object significantly smaller than the correct answer.

Overall, the responses to these five questions show that the participants do not have a strong conceptual grasp of the scale of either the Solar System or the Universe. Most participants do not have an accurate grasp of the relative distance between the Earth and the Moon, and many of the participants have a disproportionate view of the scale of the Solar System compared with the distances between observable stars.

5.2 Motion

This category contains questions 1, 2, 7, 9, 10 and 18. Question 1 identifies understanding of the motion of the Sun across the sky. Fewer than half of all teachers answered this question correctly. The most common incorrect answer for each group of participants was that the Sun is directly overhead (no shadow) every day at noon. Question 2 asked about the position of the Moon during an eclipse. Fewer than half of secondary teachers answered this item correctly. The most common incorrect answer was that there must be a full Moon. The next most common answer was that the Moon does not have to be in any particular phase for an eclipse to occur. Question 7 asked what would happen to the seasons if Earth’s orbit were circularized. Just over 25% of elementary, 50% of middle school, and 75% of high school space science teachers answered that we would experience seasons in the same way. Discussions of this test item generated some controversy, because many of the participants identified that we would experience some change, and the term "much" in two of the answers was subjective. However, just over 25% of teachers indicated that the Earth would not experience seasons if its orbit were circularized. Question 9 asked asked how the position of the setting Sun changes over time. Less than 50% of elementary teachers and slightly more than 50% of middle school teachers answered this question correctly. Nearly all high school teachers answered correctly. Question 10 asked about the motion of the Sun with respect to background stars. Fewer than 1/3 of teachers in each group answered this incorrectly. The most common incorrect answer was that the background stars stay stationary over the course of a day. Questions 18 and 19 related to the position of the Moon during specific phases, and the appearance of the Moon during the course of a night. Just 25% of elementary teachers and slightly more than 50% of middle school science teachers were able to correctly identify the position of the Moon during a specific phase. Almost 2/3 of high school teachers were able to correctly identify the position of the Moon during a specific phase. Most (more than 75%) of the participants in each group correctly answered question 19.

Overall, the responses to questions in this category showed that there is significant misunderstanding of the motions of the Earth and Moon. Many of these teachers are unable to connect the concepts of rotation and revolution to positions of the Earth, Moon, Sun, and other stars, and to observation.

5.3 Gravity

Questions 4, 6, and 14 relate specifically to the concept of gravity. Question 4 asked what would happen if you dropped two balls, identical except for weight, and ignored air resistance. The majority of teachers in each group answered correctly that they would hit at the same time. All of the teachers who answered incorrectly stated that the heavier ball would land first. Question 6 asked for the reason that astronauts float while in orbit around the Earth. Less than 10% of the elementary teachers got this question correct, while less than 50% of secondary science teachers answered this correctly. The most common wrong answers for each group were that there is no gravity in space, and that more than one of the provided answers were correct. Question 14 asked a qualitative question about universal gravitation and conditions that could be changed to decrease one’s weight. Fewer than 1/3 of elementary teachers and 1/2 of middle school teachers got this question correct. Most (84%) of the high school space science teachers answered this question correctly. The most common incorrect response for each group was that there was more than one correct answer provided. The most common incorrect condition selected was the removal of half of the Earth’s atmosphere.

The response to question 4 showed that most middle and high school teachers do have at least a basic grasp of the concept of gravity. However, question 14 showed that, in general, middle school and elementary science teachers do not have an understanding of Newton's Law of Universal Gravitation. Additionally, responses to question 6 showed that many teachers are unable to connect their understanding of gravity to orbital motion. Incorrect responses to question 6 also showed that the misconception that there is no gravity in space is prevalent in at least 40% of elementary science teachers, 20% of middle school science teachers, and 10% of high school science teachers.

5.4 General

Questions 5, 8, 15, 16, 17, and 21 relate to general physical science concepts or other concepts in astronomy. Question 5 compares the speed of radio waves with the speed of visible light. Less than 20% of elementary space science teachers and just under 25% of middle school science teachers answered this question correctly. Fifty percent of high school space science teachers answered correctly. The most common wrong answer for all groups was that radio waves travel much slower than visible light. Question 8 asked about the source of the Sun's energy. Less than 50% of middle school teachers and 20% of elementary teachers who teach science answered this correctly. Just over half of high school teachers answered correctly. The most common wrong answer for each group was that the Sun's energy comes from breaking large, heavy elements into lighter ones. Question 15 probed understanding of the inverse square law for light by asking how many light bulbs would be needed to provide the same illumination if the distance were doubled. Less than 25% of elementary and middle school space science teachers were able to answer this question correctly. Just under 2/3 of high school science teachers answered correctly. The most common incorrect answer was that you would have to double the number of light bulbs to retain the same illumination if the distance were doubled. Question 16 asked where, according to modern ideas, the center of the Universe is located. More than half of the teachers in each group answered this question correctly. The most common incorrect response was that there is an unknown distant galaxy at the center. Just over 13% of all participants indicated that the Sun is at the center of the Universe. Question 17 asked which color star is the hottest. Approximately 50% of elementary and middle school teachers and 74% of high school teachers answered correctly. Question 21 asked about the cause of global warming. Less than 25% of elementary school teachers, 50% of middle school teachers, and just over 50% of high school science teachers were able to correctly answer this question. The most common incorrect answer for all of the groups was that global warming is caused by the destruction of the ozone layer. The idea that heat is trapped by nitrogen was also prevalent with high school teachers.

Responses to questions 5 and 15 show that the participants do not have an understanding of light and the electromagnetic spectrum. This is most pronounced at the elementary and middle school levels. Responses to questions 8, 16, and 17 show that many science teachers lack an understanding of basic astronomy concepts. Additionally, the common incorrect response to question 21 indicates a prevalent misconception.

5.5 Implications for Professional Development

The purpose of this study was not to identify a deficiency in teacher content knowledge, but instead to draw attention to the importance of well-planned, high-quality professional development for in-service teachers. Because good teaching is dependant on, but not guaranteed by, a depth of content knowledge, it is important that professional development designers and facilitators have an understanding of the knowledge base of their audience.

Schmidt (2001) has identified implications of the Third International Math and Science Study (TIMSS) for professional development. He proposed that a teacher's understanding and conception of subject matter are major aspects that define teacher quality. Teachers with weak science backgrounds but an understanding of pedagogy often implement "neutered" processes where students engage in activities that are void of real science content. According to Schmidt, the biggest challenge for science reform efforts is to develop a process by which teachers may develop the subject matter knowledge needed to support science standards so that they can implement pedagogical approaches embedded in real science content. Additionally, research has shown (Cohen & Hill 2000) that professional development that is focused on academic content and pedagogy is more successful at improving both teaching practice and student achievement, as compared with professional development that is not linked to content (e.g., workshops on cooperative learning techniques or other strategies).

Currently, many professional development efforts in astronomy education focus on introducing educators to activities that can be used in the classroom. Although these activities may be provided within the context of astronomy content, explicit connections to overarching themes in the discipline are not made. Professional development efforts should focus on providing a coherent structure for astronomy, and methods for communicating that structure to students. Additionally, these opportunities should strive to provide continuing support to participants as they deepen their content understanding and change their teaching practices.

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