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Covering the Standards: Astronomy Teachers' Preparation and Beliefs

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Abstract

An online survey of science teachers and interviews with curriculum directors were used to investigate the coverage of astronomy in middle and high schools in the greater Philadelphia region. Our analysis looked beyond astronomy elective courses to uncover all sources of astronomy education in secondary schools. We focused on coverage of state standards, time spent on astronomy, availability of resources, teacher efficacy, and teacher pedagogical beliefs. Astronomy is not taught in depth, and many students receive no astronomy instruction across both middle and high school. Many teachers hold reform-based perspectives but also maintain traditional beliefs about astronomy teaching and learning. Implications for future reform efforts are discussed.

1. INTRODUCTION

Science is one of many areas that compete for children's educational time in school. Further complicating the challenge of training a scientifically literate population through K–12 schooling is the diverse range of scientific topics posed by state and national standards, including those in astronomy. Recent reform-based documents have suggested that educators and policy makers identify the concepts that are central to each domain of science and build curriculum around those "big ideas" (Corcoran, Mosher, and Rogat 2009; Duschl, Schweingruber, and Shouse 2007; Smith *et al.* 2006). Limiting science instruction to concepts with broad explanatory power will help weed out peripheral ideas and instruction that focuses on the rote memorization of disconnected facts. Students also should be allowed the opportunity to build understanding of these ideas across time as they move through elementary and secondary education (Sadler 1998). However, school science frequently tends toward disconnected facts rather than a designed focus on conceptual goals that build over time (Corcoran, Mosher, and Rogat 2009).

In order to move schools toward this reform-based agenda, educational researchers and policy makers must have a broad understanding of the ways in which science currently appears in school in order to better meet the needs of teachers and districts. As part of this effort, we discuss the ways in which astronomy is covered at the secondary level in districts sampled from southeastern Pennsylvania as well as the characteristics of the teachers who teach astronomy in this region. Through this investigation of common practices across a large geographical region governed by the same state standards, we can suggest how well astronomy is fairing in public schools and the resources available for teachers to engage students in astronomy while also measuring how well teachers are prepared to teach these concepts, both in terms of their education and their attitudes toward reform-based ideas about teaching and learning. Further, we expand our search for astronomy coverage to include astronomy as part of required courses, astronomy electives, and other opportunities for students to engage with astronomy concepts to uncover all possible ways in which astronomy is included in the secondary science curriculum. Thus, we adopt the term *teachers of astronomy* to describe the subjects of this study (rather than “astronomy teachers”) because, as we will describe below, most do not teach astronomy as their sole or primary focus.

1.1. Previous Studies On Secondary Teachers of Astronomy and Astronomy Teaching

Past research indicates that current K–12 schooling is not producing graduates with a solid understanding of elementary astronomy concepts. Many, if not most, students enter college astronomy courses with significant misconceptions about the subject (e.g., Zeilik and Bisard 2000; Zeilik and Morris 2003) suggesting that K–12 instruction has not been successful in improving children’s understanding of astronomy across many conceptual areas. Previous research on current and preservice elementary teachers have shown that many elementary teachers hold the same misconceptions about astronomy concepts as are found with their elementary-aged students (e.g., Akerson 2005; Atwood and Atwood 1995, 1996; Trundle, Atwood, and Christopher 2002; Plummer, Zahm, and Rice 2010). Brunsell and Marcks’ (2004) investigation of teachers’ astronomical knowledge found that, while middle school and high school teachers show a greater understanding of astronomy than elementary teachers and the average college student, secondary science teachers still fall short of proficiency on standard Astronomy 101 concepts. The prevalence of adult misconceptions demonstrates the need for additional reform efforts, targeting ways in which astronomy is included in K–12 schooling.

A few relevant studies provide insight into the characteristics of teachers of astronomy, including the nature of astronomy teaching in the United States at the secondary level and the abilities and beliefs of astronomy teachers. An electronic survey and separate paper-pencil survey by Krumenaker (2009a, 2009b) uncovered changes in high school astronomy since the last such investigation (Sadler 1992, p. 25), focusing on classroom and teacher characteristics. Since the original survey in 1986 (Sadler 1992, p. 25), there has been a shift in the gender of astronomy teachers from 12% female to 21–33% female. (Each Krumenaker survey yielded different gender ratios.) About half of these teachers still only teach a single section of astronomy. About 9% of schools included an astronomy elective in 1986 while currently only 3.5% include astronomy. Teachers now use websites and workshops to keep up with astronomy topics while in the past they primarily used magazines. Astronomy teachers primarily are certified as earth/space science teachers followed by physics and bioscience as the next most frequent areas of certification. Most astronomy teachers have taken one or two college-level astronomy classes, while 15% have never taken an astronomy course (Krumenaker 2009a). It is not clear whether these teachers may have taken other college-level courses that included astronomy among other topics.

Slater, Slater, and Olson’s (2009) recently investigated how teachers of astronomy use reform-based pedagogies, specifically focusing on the use of internet-supported inquiry opportunities in planetary science. Their sample includes 799 elementary, middle, and high school astronomy “alpha” teachers: “teachers that are highly effective, quick to respond to innovation, and rather ambitious in their pursuit of resources for themselves and their students (p. 5).” These alpha teachers take advantage of several sources of online data, including USGS.gov, GoogleEarth, and Volcano World, and a broad range of other data sources. Significant to our understanding of how astronomy teachers have adopted reform-based curriculum practices, the authors find that fewer than 27% of alpha astronomy teachers use open or guided inquiry. When inquiry is used, it is more often highly structured or used as part of confirmation activities. These astronomy teachers are highly interested in increasing the use of inquiry in their astronomy classrooms but indicate that the number of topics required by state standards, and the time required to do so, prevent them from increasing their use of authentic inquiry practices.

1.2. Teachers’ Beliefs About Astronomy Education

While many studies exist about teachers’ understanding of astronomy and many studies have been conducted on teachers’ understanding of the nature of science (NOS), limited research exists that examines teachers’ beliefs about how to teach astronomy. Teachers’ beliefs about how to teach science are framed by their beliefs about the NOS (Hammrich 1998) and those beliefs, in turn, influence how they choose to implement reform-based curriculum (Roehrig and Kruse 2005). Reviews of studies across elementary to high school conclude that significant limitations exist in teachers’ concepts of the NOS and that improvement in teachers’ understanding of the NOS requires instruction that is both explicit and reflective (Abd-El-Khalick and Lederman 2000; Lederman 1992). Many teachers believe that science is an objective body of knowledge created through a strict process called the scientific method (Brickhouse 1990; Gallagher 1991). Teachers’ limited understanding has been attributed to their lack of targeted formal training on the NOS (Gallagher 1991). In recent years, studies have described elementary teachers' beliefs about the NOS in the context of astronomy investigations. Abell, Martini, and George (2001) found that even while preservice elementary teacher-participants in a phases-of-the-moon guided inquiry investigation appreciated the features of NOS that coincided with their own learning processes, they were unable to make the connections to how scientists work. In a study of elementary teachers participating in a *Physics by Inquiry* professional development workshop, Akerson, Hanson, and Cullen (2007) concluded that "an improved understanding of the NOS can be gained by allowing teachers to experience science through inquiry that is connected to an explicit-reflective NOS approach" (p. 769) and those who made the strongest connections between the inquiry activities and the NOS instruction were able to describe how they could use the NOS concepts in their existing lessons. Fortunately, there is some indication that preservice teachers who adopt reform-based beliefs in their teacher education programs will continue to hold those beliefs as beginning science teachers (Marbach-Ad and McGinnis 2008).

Beyond limited understanding of the NOS, secondary science teachers hold additional alternative beliefs about teaching and learning that conflict with reform-minded practices. Tobin and McRobbie (1996) identified cultural myths held by secondary science teachers, including the beliefs that teachers transmit knowledge to students, covering all required content is necessary, and teaching should prepare students for exams. Haney and McAurthur (2002) examined secondary science teachers' beliefs and practices using constructivist learning theory as a lens. They found that teachers were able to "put into practice" specific constructivist beliefs, including student negotiation, scientific uncertainty, and the importance of personal relevance but not the idea of sharing control with the students. The major conflicting belief for these teachers was that they must adhere to the existing local science curriculum. In a study of experienced high school science teachers, Wallace and Kang (2004) found that teachers held conflicting beliefs about teaching and learning. Those beliefs that prevented teachers from enacting reform-based teaching strategies were "more public and culturally-based while the belief sets that promote inquiry were more private and based on the individual teacher's notion of successful science learning" (Wallace and Kang 2004, p. 957). These beliefs are prevalent in teacher-culture and must be considered carefully when attempting to reform classroom instruction (Wallace and Kang 2004). Given the extent of these beliefs, implementing inquiry-based teaching is challenging in current school culture (Wallace and Kang 2004).

These studies of teacher-beliefs give us insights into what we might expect to find among teachers of astronomy. From the study of Slater, Slater, and Olson (2009), we can estimate the level to which highly qualified "alpha" teachers have adopted practices and beliefs consistent with the last few decades of reform efforts in science education, such as the use of guided inquiry (e.g., American Association for the Advancement of Science 1993; Duschl, Schweingruber, and Shouse 2007; National Research Council 1996, 2000). And their responses to questions about why they do not engage in inquiry-based instruction in their classrooms (lack of time and extensive standards) suggest that many of these teachers understand and agree with the importance of these recent reform efforts. Yet these are "alpha" teachers, participants chosen for their likelihood to adopt innovative practices. Their interests and beliefs may not be the same as the average teacher of astronomy, suggesting that further investigation is necessary to uncover the full spectrum in U.S. schools.

1.3. Goals of This Study

Astronomy's relegation to elective status among more commonly required science courses (biology, chemistry and physics) dates back to the 1892 Committee of Ten (Bishop 1990). Yet current National and State Standards include astronomy through high school. Thus, we chose to not limit ourselves to investigating those teachers who offer astronomy elective courses but to examine all possible places within the secondary curriculum that include astronomy concepts in order to give as much breadth as possible to our investigation of secondary astronomy instruction. We chose to conduct our study among teachers in the state of Pennsylvania as we had access to a database of contact information for science teachers and curriculum directors across thirty school districts. But this also allowed us to conduct this as a case study of the connection between one state's standards and the implementation of those standards across districts of varying size, socioeconomic status, demographics, and location (rural through urban).

This study will answer the following research questions in order to help astronomy educators understand the extent to which astronomy concepts are studied in secondary school, based on their coverage in school curricula, and consider teacher preparation and pedagogical beliefs in this content area:

1. To what extent do middle schools and high schools in the Greater Philadelphia area cover Pennsylvania state science standards in astronomy?

2. Do teachers who are teaching astronomy in middle school and high school feel that they are prepared to teach these concepts?
3. What are teachers' pedagogical beliefs about astronomy in the classroom?

2. METHODOLOGY

2.1. Participants

An email was sent to 507 middle school and high school science teachers in the National Science Foundation-funded Math and Science Partnership of Greater Philadelphia database from 30 school districts in the Greater Philadelphia Area. This email requested that teachers complete an online survey. Ninety-five teachers responded though only 60 of these reported that they teach astronomy content in one or more classes. Participants included 32 high school teachers, 25 middle school teachers, two teachers in a ninth-grade only school, and one who did not indicate a grade level. Participants reported on the astronomy content taught in a total of 72 separate courses. (Some teachers taught more than one specific course that covered astronomy content.) These teachers were drawn from 22 Pennsylvania school districts across six counties in the Greater Philadelphia area (with one teacher not reporting their district's name).

E-mails were sent to administrators in the same 30 school districts requesting participation in a survey about coverage of astronomy and availability of resources in their respective districts. This was done to triangulate with the data collected from the teachers. Nine administrators (with titles such as curriculum director, director of teaching and learning, and lead teacher) responded to the request by either agreeing to be interviewed over the phone or responding to the questions via email. (Four of these participants also made available curriculum documents from their school districts.) Combining those school districts from which we have either data from teachers of astronomy or curriculum director surveys yields 24 districts. This study draws from a range of district sizes and includes large suburban ($N=16$), rural ($N=4$), city (small and midsize, $N=3$) and a town ($N=1$) (National Center for Education Statistics 2009). The average number of middle school students in a district was 1487 (SD=1280; low of 328, high of 5844; $N=22$), and the average number of high school students was 2248 (SD=1894; low of 466, high of 9328; $N=22$).

To estimate the diversity of characteristics of the sampled districts, a variety of demographic data was drawn from the Math and Science Partnership of Greater Philadelphia database. Additional information (to fill in where Math and Science Partnership of Greater Philadelphia data was missing and to report percentages of students receiving free or reduced lunch) was drawn from the Great Schools database (GreatSchools, Inc. 2008). Data was unavailable for two districts. Diversity estimates reported here were drawn from the high school data set as this appeared to be closely mirrored by the middle school data. Most districts surveyed (68%; $N=22$) reported limited diversity of student population with 83% or more of the student body reported as White. (In these schools the next most populous minority was less than 10% of the student body.) Eight of these districts reported their student body as 90% White. Seven districts showed more diversity in their student bodies (Hispanic, Black, or Asian students representing 10% or more of the student body). In four districts, three ethnicities had more than 10% of the student population. In two districts, Hispanic students were the majority population (53% and 51%).

We also were able to estimate the range of relative affluence of the reporting districts through reports of students receiving free or reduced lunch as well as estimate the education background of the community through the frequency of residents with high school diplomas and four-year degrees. The average percentage of students receiving free or reduced lunch in middle school was 15% (SD=16%; low of 0%, high of 60%; $N=21$ districts) and for high school was 20% (SD=20%; low of 3%, high of 77%; $N=21$ districts). The average percentage of adults with high school diplomas in the community of the districts was 91.2% (SD=4.4%; low of 77.6%, high of 96.4%; $N=20$ districts). The average percentage of adults with a four-year college degree in the community of the districts was 34.2% (SD=15.4%; low of 17.1%, high of 68.5%; $N=20$ districts).

Students in these districts are relatively well prepared in terms of overall time spent on science, as measured by the average number of college preparation science courses taken by students. The average number of college prep science courses taken in the districts was 3.60 (SD=0.70; low of 1.62, high of 4.96; $N=19$), and the average number passed was 3.42 (SD=0.73; low of 1.56, high of 4.94; $N=19$). The majority of districts report high numbers of students planning to attend post-secondary school (average across the districts: 85%, SD=11%; low of 58%, high of 98%; $N=18$).

2.2. Data Collection

Teachers participated by responding to an online survey (see Appendix A). This survey included: Coverage of state standards, available resources, preparation to teach astronomy, and beliefs about teaching and learning. State standards in Pennsylvania (Pennsylvania Department of Education 2002) specify a range of scientific concepts that students should learn by specific grade points (4th, 7th, 10th and 12th grades; see Appendix A for relevant 7th–12th grade standards); however, new, unpublished standards have been written as of June 2009, which alter the structure and organization of astronomy in Pennsylvania standards. Two of the 2002 standards are conceptually problematic (3.4.10.D.4: Explain the "red-shift" and Hubble's use of it to determine stellar distance and movement; 3.4.12.D.3: Correlate the use of the special theory of relatively and the life of a star). For the second, we broke up the standard into two statements "special relativity" and "life of a star" in the survey.

The Pennsylvania standards differ from the National Science Education Standards (NSES) (National Research Council 1996) in several key ways. First, some concepts that are considered appropriate for 5–8 grades by the NSES (predictable motions such as day, year, phases of the Moon, eclipses as well as the reason for the seasons) are considered appropriate for inclusion by fourth grade in the 2002 Pennsylvania standards. Second, the formation of the Solar System is included as a target for 9th–12th grade in the NSES but is missing from the Pennsylvania standards. Third, the 2002 Pennsylvania standards include several topics that are not emphasized specifically in the NSES: instrumentation for exploring the Universe, accomplishments of past and present astronomers, the space program, life cycle of stars, stellar distances, the magnitude system, the impact of Copernican and Newtonian thinking, and the special theory of relativity. Overall, the astronomy portions of the 2002 Pennsylvania standards are not as concisely organized around central themes of astronomy and space science, as compared to the NSES.

The final portion of the online survey was adapted from the *Beliefs about Reformed Science Teaching and Learning* (BARSTL) questionnaire (Sampson and Benton 2006). BARSTL was designed for prospective teachers and "draws on the philosophy of the current national science education reform efforts in order to define a traditional-reformed pedagogical content belief continuum that can be used to map teachers' beliefs about the teaching and learning of science" (p. 1). The authors evaluated their survey for reliability and validity with 146 students in an Elementary Science Methods course. The use of the BARSTL allows us to collect information and assess attitudes from a range of topics but we recognize that our application of a survey method has a limitation because we are relying on the teachers to accurately report personal information. The original BARSTL measured teachers' beliefs on four constructs: how people learn about science, lesson design and implementation, characteristics of teachers and the learning environment, and the nature of the science curriculum. In the interest of reducing the length of our survey, we dropped the construct items relating to *how people learn about science*. The survey includes eight statements relating to each of the four constructions. Half of the statements are worded to reflect a reform perspective. The remaining statements reflect a traditional perspective. For our use, we replaced the word "science" with "astronomy" (except in a few instances where it would not make sense in the statement) to engage the respondents in thinking about their specific pedagogical beliefs about astronomy. Respondents were asked to indicate their agreement or disagreement on a four-point scale for each of the 24 statements. The purpose of this survey was to measure the tendency of teachers to be more reform-minded versus traditional in their beliefs about astronomy teaching.

Administrators responded to questions either via email ($N=5$), in person ($N=1$), or in a phone interview ($N=3$), at their convenience (see Appendix B for interview questions.) For the phone and in-person conversations, responses were typed during the course of interview and key facts were confirmed verbally. Questions asked for information on any courses in the administrator's district that covered astronomy content, a general description of that content, the extent to which the course is required of all students, and any resources available for teaching astronomy in the district (such as curricula or a planetarium).

2.3. Analysis

Survey questions were designed to uncover trends relating to the three initial research questions. For demographic questions on our survey, analysis was a straight-forward summary of trends found through examining a histogram or ranking number of responses in a frequency table. Responses to open ended questions required us to create sets of codes to summarize written responses before looking for trends in histograms. Simple coding schemes were created to summarize results from teachers' description of: the type of course they teach, the concepts covered in their courses (when they mentioned concepts outside of the 7–12 standards), resources available for teaching astronomy, and concepts that they did not feel comfortable teaching. The second author coded all of the data while discussing the application of the coding scheme with the first author. Discussions led to modifications, and ultimately both authors reviewed and agreed upon the final coded data.

For each of the three belief categories (*The Nature of the Astronomy Curriculum, Lesson Design and Implementation, Characteristics of Teachers and the Learning Environment*) in the BARSTL, half of the items were written such that a reform-oriented teacher would agree and half were written such that a reform-oriented teacher would disagree. Table 1 describes the characteristics of each of these three categories and the corresponding reform and traditional perspectives. Participants responded by choosing strongly disagree, disagree, agree, or strongly agree for each item. The items were scored as 1, 2, 3, and 4, respectively, for the responses: Strongly Traditional (1), Traditional (2), Reformed (3), and Strongly Reformed (4). In other words, a "strongly traditional" oriented teacher would choose "strongly agree" to traditional-perspective statements and "strongly disagree" to reform-oriented statements. A higher mean score indicates reform-oriented teachers; a lower mean score indicates traditional beliefs about teaching and learning. The use of mean scores is limited with ordinal data; however, this technique is helpful in identifying trends.

Table 1. Aspects of the BARSTL: Teachers' pedagogical beliefs about science [astronomy] teaching (the following text originally appeared in Sampson and Benton, 2006)

BARSTL Scales	Traditional Perspective	Reformed Perspective
The Nature of the Science [*Astronomy*] Curriculum	Focus on basic skills (foundations)	Focus on conceptual understanding and the application of concepts
	Curriculum is fixed Focus on breadth over depth	Curriculum is flexible, changes with student questions and interest Focus on depth over breadth
Lesson Design and Implementation	Teacher-prescribed activities	Student-directed learning
	Frontal teaching—telling and showing students Relies heavily on textbooks and workbooks	Relies heavily on student developed investigations, manipulative materials and primary sources of data
Characteristics of Teachers and the Learning Environment	The teacher acts as a dispenser of knowledge	The teacher acts as facilitator, listener, and coach
	Focus on independent work and learning by rote	Focus on learning together and valuing others ideas and ways of thinking

For each of the 24 items, the mean and standard deviation were calculated, and then an overall mean and standard deviation was calculated for each of the three categories. A mean score of 2.5 suggests a neutral average response. We were also interested in determining the distribution of "types" of teachers as measured by this survey (e.g., traditional or reform-minded). To do this, we calculated the mean for each teacher for each of the three categories for both reform items and traditional items. For each of the three categories, we used these means to classify the teachers as *reform*, *agreeable*, *neutral*, *contrary*, and *traditional.* (see Table 2)

Table 2. Categories used to classify teachers pedagogical beliefs about astronomy teaching according to their responses to reform items and traditional items on the BARSTL

	Reform Items			Traditional Items		
Teacher Classifications	**Agree**	**Neutral**	**Disagree**	**Agree**	**Neutral**	**Disagree**
Reform: Agrees with reform items; neutral or disagrees with traditional items ($R_{\text{mean}} \geq 3; T_{\text{mean}} > 2$)	X				X	X
Agreeable: Agrees with both reform and traditional items ($R_{\text{mean}} \geq 3; T_{\text{mean}} \leq 2$)	X			X		
Neutral: Neutral for both reform and traditional items ($2 < R_{\text{mean}} < 3; 2 < T_{\text{mean}} < 3$)		X			X	
Contrary: Disagrees with both reform and traditional items ($R_{\text{mean}} \leq 3; T_{\text{mean}} \geq 3$)			X			X
Traditional: Disagrees or neutral with reform items; agrees with traditional ($R_{\text{mean}} < 3; T_{\text{mean}} \leq 2$)		X	X	X		

3. RESULTS

3.1. Research Finding 1: Astronomy is Covered for Short Spans of Instructional Time Across a Range of Courses at the Secondary Level

Astronomy concepts are covered across a range of different courses in the Greater Philadelphia area. Astronomy content is covered in traditional courses such as astronomy (11%), earth and space science (course names included "earth science;" 26%), physics and physical science (19%), and integrated or grade-level science courses (28%). Astronomy content also is covered in unanticipated courses such as: biology, environmental science, chemistry, and marine science (15%). Many classes cover astronomy for 2 weeks to a month (24%) or 1–2 months (24%). Fewer include astronomy for more than 2 months (15%) while 38% responded that astronomy is covered for less than 2 weeks in their course. Examining the distribution of length of time spent on astronomy as a function of grade level (Table 3) reveals that, in general, astronomy tends to be covered for longer periods of time in the middle grades compared to in high school. (The two freshmen center classes and one unknown-grade-level class are not included on this table; each covers astronomy for more than 2 months.)

Table 3. Distribution of length of time spent on astronomy for middle and high school

	$<$1 week	1–2 weeks	2 weeks–1 month	1–2 months	$>$2 months
Middle school (N=37)	2 (5%)	6 (16%)	13 (35%)	12 (32%)	4 (11%)
High school (N=32)	10 (31%)	9 (23%)	4 (13%)	5 (16%)	4 (13%)
Total (N=69)	12 (17%)	15 (22%)	17 (25%)	17 (25%)	8 (12%)

Improvement in students' understanding of science requires that teachers provide students the opportunity to go into more depth on fewer concepts rather than cover many concepts in short periods of time (e.g., Schwartz *et al.* 2009). This led us to wonder whether teachers of astronomy provide the opportunity for depth or breadth in their coverage of astronomy. To estimate the concentration of astronomy standards in the classes surveyed, we calculated a ratio that we refer to as the *instructional intensity*: the amount of time spent in class per astronomy standard. First, to calculate this ratio, values were assigned to the time spans indicated in the survey: <1 week$=1$ week; $1-2$ weeks$=2$ weeks; 2 weeks-1 month$=4$ weeks; $1-2$ month$=8$ weeks; >2 months$=12$ weeks. This gave us an approximate scale for length of time spent on concepts. The *instructional intensity* value was calculated as the ratio of "time length" divided by "number of standards." A high number would represent depth into astronomy content, while a small number indicates breadth in astronomy coverage. In the "number of standards," we also included additional topics that teachers mentioned covering that were outside of the scope of the Pennsylvania 7th, 10th, and 12th grade standards. Figure 1 shows the instructional intensity ratio as a dimensionless quantity representing number of standards covered per unit of instruction time. While an imperfect measure, this suggests that most classes (90%) are spending a week or less per standard and half (50%) spend approximately half a week per standard. Another way of looking at this is to consider the inverse, number of standards per week of instructional time. Most teachers (61%) are covering between 1 and 3 standards per week of instructional time. These estimates are supported by the interviews with the nine district curriculum developers. Astronomy is not required study for longer than 3 months in any of the 9 reporting districts. However, all described three or more significant areas of astronomy studied during these time frames. Thus despite only short periods of time being dedicated to astronomy at the middle and high school level, many topics of astronomy are included in each class.

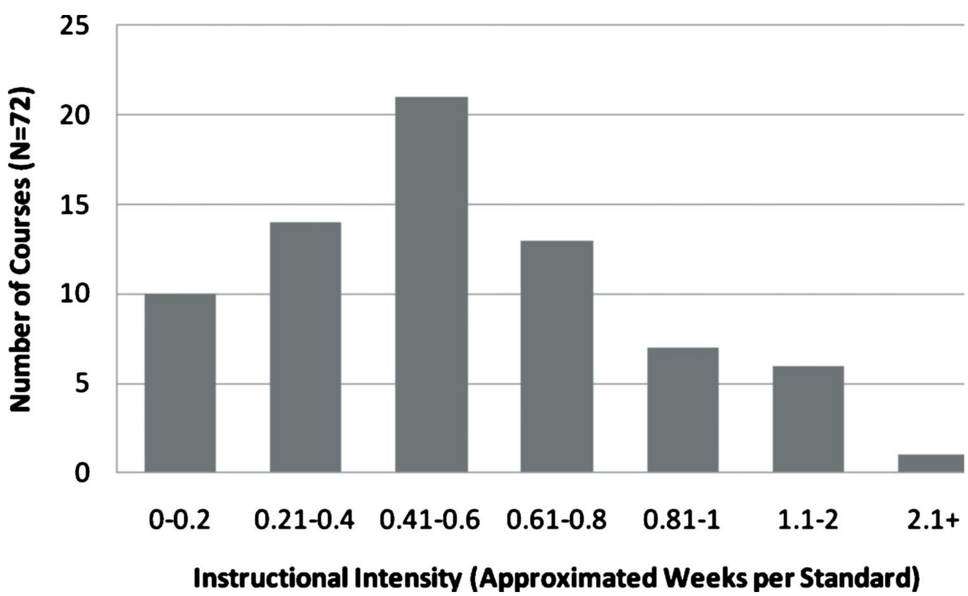

Figure 1. Graph showing an estimate of instruction intensity per course; instructional intensity is an approximate measure of the amount of time spent (measured in weeks) per astronomy standard (N=72)

3.2. Research Finding 2: All Pennsylvania Standards in Astronomy are Represented across the Districts Sampled but Astronomy is Not Taught at Middle and High School in All Districts

The curriculum director interviews (N=9) allowed us to consider how often astronomy is included in the secondary curriculum in this state. Astronomy is not *required* for students in three districts (though it is included in an elective course or courses for students in a specific "track"). This contrasts with two districts that require students to study astronomy at both the middle and high school level. Overall, six out of nine school districts require astronomy at the middle school level. All six cover astronomy for less than half of a school year ranging from as little as a month to as long as 8–12 weeks.

Only two districts require astronomy at the high school level, covered for a month in one and 6 weeks in the other program. For an additional six districts, astronomy is part of electives at the high school level. Two districts have more than half of the students choose to take an elective course that includes astronomy. In one, 75% of students choose this course as one of their required science courses. In the other district, 60% of the lower track students in the district take this as a required integrated science course. A full astronomy course also is offered in this district as an elective (1–3 sections per year).

We analyzed the data in three ways to determine the extent to which the standards are currently being taught across the 24 districts surveyed. First, we examined the frequency of inclusion of each standard across the 72 courses described by the teachers. Second, we examined the frequency of inclusion in all of the *required* courses among the nine curriculum directors. Finally, we combined the interview data from the curriculum directors and the teacher surveys to analyze the frequency of coverage (in both required and elective courses).

All Pennsylvania astronomy standards are covered to varying extent across the 22 school districts represented by the teachers in the survey. Figure 2 shows the six most frequently included standards and the five least frequently included standards among the courses surveyed. (Ninth grade only schools are included in the middle school section of the graph for this analysis.) Stellar evolution is the main topic of two standards (3.4.10.D.2 and 3.4.10.D.3.2) so the total number of courses including either standard is presented in Figure 2. Appendix C includes the full list of 19 standard statements, organized by grade level and standard number, with statistics for both middle and high school.

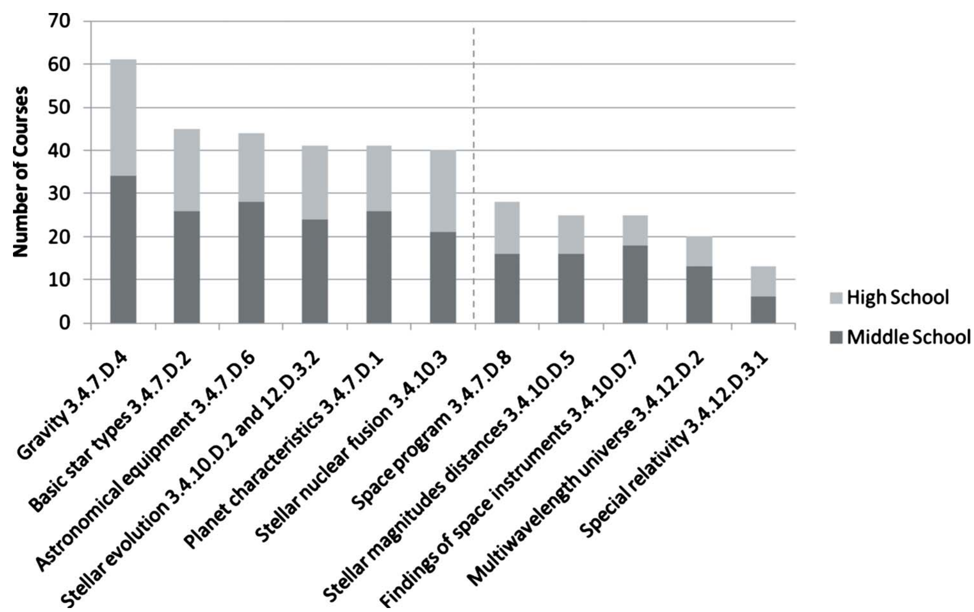

Figure 2. Graph showing the six most frequently and five least frequently included standards as estimated across all courses; frequency of middle school and high school for each standard is also shown (N=72)

Gravity's role in explaining motions in astronomy is the most often covered concept in secondary science classrooms. Other major concepts include stars and stellar evolution as well as characteristics of the Solar System and instruments of investigation, relating to the Solar System. Note that these are dominated by concepts from the middle school level standards. High school standards relating to the findings from space instruments, stellar magnitudes, special relativity, and understanding astronomy across the electromagnetic spectrum were covered by the fewest teachers. Teachers also were asked to write in any astronomy concepts that they cover that are not part of the 7th, 10th, or 12th grade science standards. These included: lunar concepts, Sun-Earth-Moon system, spectral analysis, and the seasons. All of these except "spectral analysis" are included in standards to be met by the fourth grade. As expected, there were some differences between the most frequently taught concepts at middle and high school. For both groups, gravity and describing basic star types were among the most frequently studied. High school classes also included nuclear fusion and the life cycle of the stars frequently while middle school classes were most likely to include topics relating to the Solar System as well as equipment and instrumentation used to explore the universe.

The curriculum director survey allows us to be reasonably confident of the standards that are required in those nine districts (see Appendix D for the full description). Only four standards are required to be taught by the majority of the nine districts surveyed with curriculum directors: characteristics of planets (N=6), comets, asteroids, and meteors (N=6), Solar System motions (N=6; a fourth grade standard), and the use of gravity to explain motion (N=5). Six standards were not required by any of the nine districts; all of these were 10th and 12th grade standards.

Combining the curriculum-director surveys and the teacher surveys allows us to estimate the magnitude of coverage of each standard across the area at the district level (Figure 3). This is an estimate because of the voluntary nature of the survey and the teacher-survey data combines both courses required for all students and courses that are only taken by some students in each district. Based on this analysis (Appendix D), standards included in 75% or more of the districts include characteristics of solar-system objects, gravity, the Sun and other types of stars, and astronomical instrumentation. This roughly agrees with the analysis of required courses and the course-by-course analysis except that solar system motions were mentioned more often in the district-required courses and stellar evolution ranked higher in the teacher-survey course-by-course analysis. The solar-system motions topic's low priority in the full district-by-district analysis can be explained; this is a fourth grade standard so was not on the list of standards teachers could select from in the survey. Conversely, the curriculum director interviews gave us access to the full list of topics actually required in the district courses,

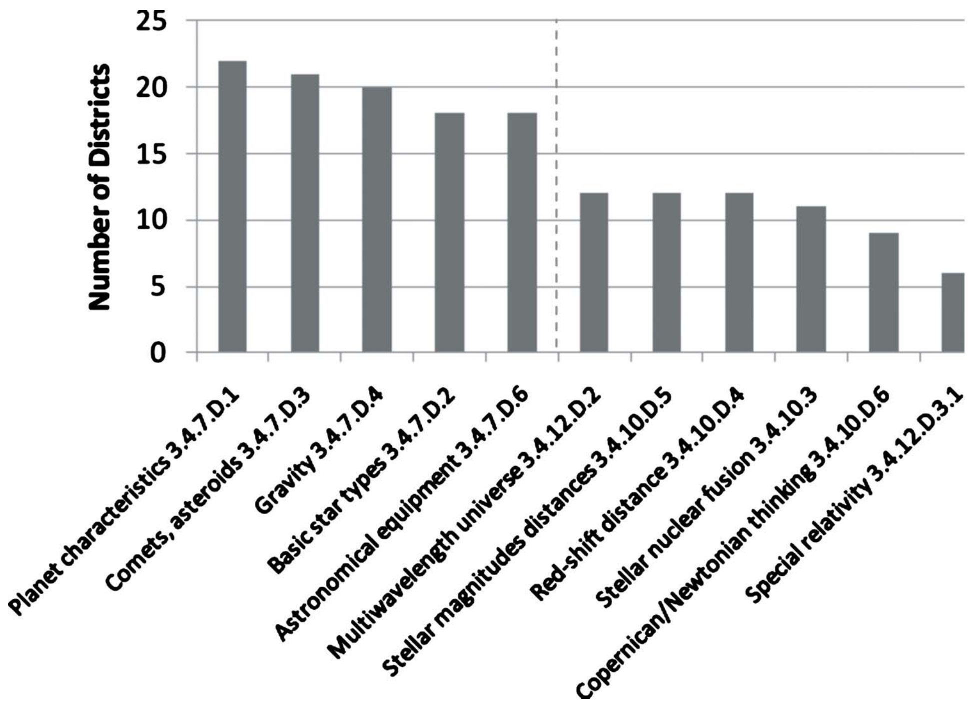

Figure 3. Graph showing the five most frequently and six least frequently included standards by each district in the sample (N=24)

and the interviews were not constrained by a list of standards. Concepts of stellar evolution were only mentioned in 50% of the districts, suggesting that these districts were over represented in the teacher survey compared to other districts.

Finally, we examined the overall coverage of standards as a fraction of the total number of standards. Eleven districts cover less than 50% of the secondary astronomy standards, with four covering three (16%) or fewer standards. Of the remaining eleven districts which reported including more than 50% of the astronomy standards for 7th, 10th, and 12th grades, nine districts cover 18 (N=5) or 19 (N=4) secondary astronomy standards.

3.3. Research Finding 3: Most Teachers Feel Prepared To Teach Astronomy Topics in Their Course and Have a Range of Astronomy Resources Available to Them

One promising result of this survey is that most teachers responded that they agree or strongly agree with the statement "I feel prepared to teach astronomy" (81%; $N=59$). We investigated teachers' preparation in astronomy, including college courses and professional development opportunities, as well as their access to various astronomy-related resources to help us understand their positive feelings toward their preparation in astronomy. More than half had taken a college-level astronomy course ($N=36$; 61%) and a third of the teachers ($N=20$; 34%) had taken more than one course. Teachers also mentioned a range of types of professional development opportunities. Nineteen teachers (32%) mentioned some form of professional development. Workshops were mentioned by 12 teachers, including Project Astro, National Aeronautics and Space Administration (NASA) Explorer School, Space Camp, astronomical society meetings, conference sessions, and other NASA-sponsored workshops. Three teachers described memberships in local astronomy societies and three referred to their professional development in terms of their own personal exploration and work, such as reading about astronomy or writing their own curriculum to address state standards. One teacher has taught colleagues how to use the school planetarium for use in their curriculum. Most teachers also expressed interest in future professional development opportunities in astronomy (21 strongly agreed (36%), 32 agreed (55%), and only 5 disagreed (9%)).

The eleven teachers who did not feel prepared to teach astronomy included seven high school teachers (two who teach chemistry, two who teach physics, a physical science teacher, and two integrated science teachers) and four middle school teachers (three who teach integrated science courses and one who teaches an astronomy course). Only one of these teachers previously had taken an astronomy class (compared to 61% of teachers overall in the survey) and only two had some form of professional development (though for one it was only focused on the Sun; this compares to the 32% of teachers overall who have had professional development). All but one of these teachers expressed interest in participating in professional development in astronomy. (The one who did not is a chemistry teacher who spends less than a week on astronomy.)

Teachers were asked to report the areas in which they feel most comfortable teaching and the areas they feel least comfortable teaching. (Fifty teachers responded to this section.) From this, we get a sense of areas that likely are not covered well in secondary school because teachers' lack confidence. Perhaps not surprisingly, the areas teachers felt most comfortable teaching corresponded to areas that they indicated that they teach. Ten teachers (20%) said that they felt comfortable teaching all or almost all aspects of astronomy. We combined these ten teachers' responses with the individual responses by the remaining teachers, coding their responses to correspond to categories based on the standards. The largest portion of the teachers expressed confidence in teaching solar-system ($N=28$) or/or stellar evolution ($N=28$) while more than a third of the respondents indicated confidence in the contribution of scientists ($N=22$), gravity ($N=19$), the space program ($N=19$), the big-bang theory ($N=19$), and nuclear fusion ($N=18$). Only a few teachers mentioned lack of confidence in teaching most aspects of astronomy ($N=5$). The remaining teachers mentioned a few topics in which they were not confident in teaching. Not including the five with little confidence in teaching astronomy, the only topics mentioned by more than five teachers were: constellations ($N=8$), the physics of astronomy including celestial mechanics ($N=7$), and relativity ($N=5$).

Figure 4 shows the frequency of availability of various astronomy-related resources. The last three categories (kits, field trips, observational equipment) were created based on teacher's write-in responses to this question (options that we did not anticipate and were not included for all teachers). As expected, most teachers use websites (98%) and textbooks (90%) as a resource. A surprisingly high percentage (50%) indicated that they have a planetarium available for instructional use (including in-house, fieldtrips (12%) and STARLAB) or access to a telescope (37%). This is comparable to our finding that five out of the nine curriculum directors interviewed included planetariums as a resource for their district. We did not specifically ask about the nature of the software used by 47% of the teachers, but this may include planetarium software; Krumenaker (2009b) estimates that 15% of high school astronomy teachers (teaching a specifically designated astronomy course) use such software. Our survey does not reveal how often or in what ways these resources are used. However, it is encouraging to see the extent that astronomy teachers have resources for their teaching. Additional resources mentioned by teachers included: star charts, videos, NASA materials, binoculars, field trips, science kits, and spectroscopes.

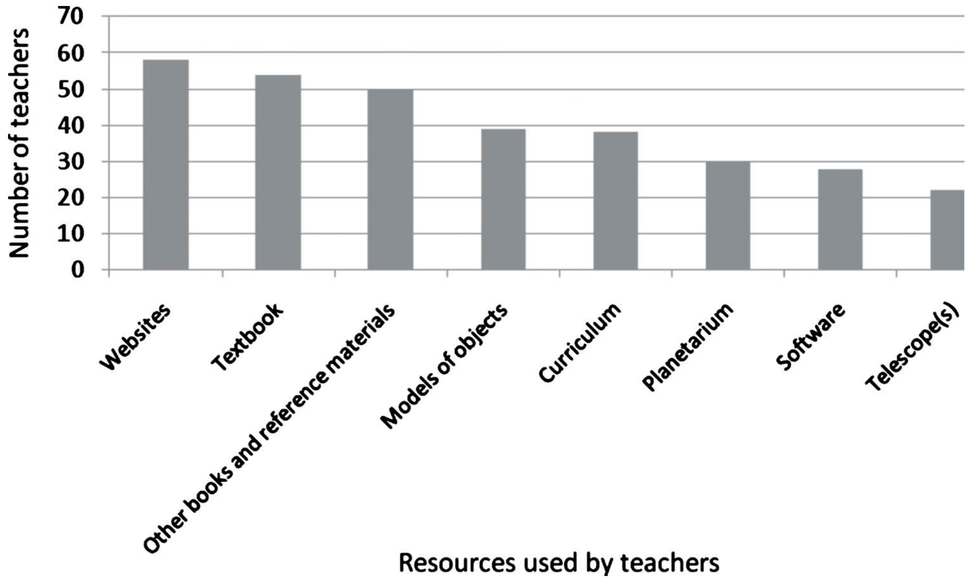

Figure 4. Graph showing the frequency of teachers for which various astronomy resources are available ($N=60$)

3.4. Research Finding 4: Most Teachers Agree with Reform-Based Perspectives Toward Astronomy Education but Many Retain Traditional-Based Beliefs as Well

Fifty-six teachers responded to survey questions concerning astronomy teaching beliefs, though not all teachers answered all items. Reform-oriented items are indicated by the letter *R*; traditional-perspective items are indicated by the letter *T* (Tables 4–6). A mean score of 2.5 suggests a neutral average response with an equal spread of reform and traditional responses. Higher mean scores indicate responses from a reform-oriented perspective, and lower mean scores indicate traditional beliefs about teaching and learning. For example, in Table 4, the mean response to Statement 2 is 2.0. This means that, on average, teachers responded to this question from a traditional perspective, agreeing with the question. The response to Statement 5 is a mean of 3.4, which means that the teachers responded from a reform-based perspective and agreed with the statement.

Average responses for each of the three categories in this survey tended toward neutrality between traditional and reform-oriented beliefs (*The Nature of the Astronomy Curriculum:* Mean=2.6, SD=0.6; *Lesson design and implementation:* Mean=2.8, SD=0.5; *Characteristics of teachers and the learning environment:* Mean =2.8, SD=0.4). Collapsing the three categories to just look at averages for traditional and reform items we found that, on average, teachers agreed with reform items (Mean=3.0, SD=0.4) and were neutral on traditional items (Mean=2.5, SD=0.5). This suggests that while teachers recognize and value reform-oriented statements, they do not discriminate against traditional practices and beliefs. A closer look at individual statements provides additional information on their perspectives on the NOS, inquiry, depth versus breadth, and student-centered classrooms. Responses to statements relating to *The Nature of the Astronomy Curriculum* (Table 4) suggest these teachers have a limited view of the NOS; they support the traditional perspective that a single "scientific method" is used to conduct research in astronomy. While the teachers believe that students should focus on scientific reasoning and use multiple methods to solve problems, they do not approach the use of inquiry from a reform-based perspective (such as described in *Inquiry in the National Science Education Standards* (National Research Council 2000)). Specifically, they do not see investigations as the method of teaching content but rather as confirmation activities, conducted after students have learned new concepts through other methods. Thus, even though they agree that students should learn via inquiry, their definition of inquiry does not seem to match that of science-reform documents. On average, teachers were neutral in their beliefs about whether it is important to go into depth on a few topics versus covering many topics. A closer look at the data confirms that this is because a large portion of the teachers support the traditional perspective (covering as many topics as possible) and disagree with the reform-minded belief (include a few concepts but in depth). Similarly, many of the responders hold a teacher-centered perspective, rather than a student-centered perspective in which they would believe that the students should do most of the talking in class, students should help determine the direction of the lessons, and that students should work collaboratively rather than independently.

Table 4. The nature of the astronomy curriculum (the following text originally appeared in Sampson and Benton 2006). *T*=traditional item; *R*=reform-based item; scale is from 1 (highly traditional) to 4 (highly reform-based); the words in brackets replace the original words: "science" and "scientific"

	Mean	SD	Total
1. Students should learn that all science is based on a single scientific method—a step-by-step procedure that begins with 'define the problem' and ends with 'reporting the results.' *T*	2.3	0.9	$N=55$
2. The astronomy curriculum should focus on the basic facts and skills of [astronomy] that students will need to know later. *T*	2.0	0.5	$N=53$
3. Students should know that [astronomical] knowledge is discovered using the scientific method. *T*	1.8	0.6	$N=56$
4. In order to prepare students for future classes, college, or a career in science the science curriculum should cover as many different topics as possible over the course of a school year. *T*	2.6	0.8	$N=55$
5. The [astronomy] curriculum should help students develop the reasoning skills and habits of mind necessary to do science. *R*	3.4	0.5	$N=56$
6. The [astronomy] curriculum should encourage students to learn and value alternative modes of investigation or problem solving. *R*	3.3	0.6	$N=55$
7. A good science curriculum should focus on the history and NOS and how science affects people and societies. *R*	3.1	0.6	$N=55$
8. A good [astronomy] curriculum should focus on only a few astronomy concepts a semester, but in great detail. *R*	2.5	0.6	$N=53$
Cumulative	2.6	0.6	

After calculating the overall teacher averages as well as traditional-item and reform-item averages, we wondered whether we could identify different populations of teachers based on their responses. Specifically, we wondered if, in general, teachers were agreeing to both traditional and reform items—if there were groups of reform and traditional teachers that were balancing out in the average or there is some other explanation for the general responses we observed. To answer these questions, we considered ways to classify the teachers for each of the three categories of beliefs questions. In addition to *reform*-minded and *traditional*-minded teachers, we found teachers whose responses were neutral on average (*neutral)*, teachers who agreed with both traditional and reform items (*agreeable)* and teachers who disagreed on average with both types of items (*contrary)*. The results of this categorization are found in Table 7. There is significant difference among the frequencies with which teachers are classified on their beliefs about The Nature of the Astronomy Curriculum ($N=56; \chi^2(4)=27.393, p<0.001$), Lessons Design and Implementation ($N=56; \chi^2(4)=61.679, p<0.001$), and Characteristics of Teachers and the Learning Environment ($N=56; \chi^2(4)=63.107, p<0.001$).

This new analysis paints a different picture of the teachers in our survey. In their beliefs about *The Nature of the Astronomy Curriculum*, the same numbers of teachers (36%) were classified as "reform" and "agreeable" (agreeing to reform and traditional statements). A larger portion of teachers were classified as "traditional" (14%) in this category than the other two categories. This distribution of responses led to the generally neutral response overall. Thus, while 72% of the teachers responded favorably to reform items, 50% also favored traditional responses. In this area particularly, many teachers have assimilated reform-based beliefs alongside traditional ones rather than replacing those traditional beliefs. Just as has been found in conceptual change literature, where students hold non-scientific beliefs alongside scientific beliefs (e.g., Vosniadou and Brewer 1992, 1994), teachers beliefs can include aspects of both reform and traditional perspectives. While course work, professional development, and school culture has favorably shifted teachers' thinking toward a reform approach, it has not confronted their misconceptions about best practices in curriculum development.

Table 5. Lesson design and implementation (the following text originally appeared in Sampson and Benton 2006). *T* = traditional item; *R* = reform-based item; scale is from 1 (highly traditional) to 4 (highly reform-based); the words in brackets replace the original word: science

	Mean	SD	Total
1. Assessments in science classes should only be given after instruction is completed; that way the teacher can determine if the students have learned the material covered in class. *T*	2.9	0.7	*N* = 56
2. During a lesson, all of the students in the class should be encouraged to use the same approach for conducting an investigation or solving a problem. *T*	3.0	0.5	*N* = 54
3. Whenever students conduct an investigation during an [astronomy] lesson, the teacher should give step-by-step instructions for the students to follow in order to prevent confusion and to make sure students get the correct results. *T*	2.7	0.7	*N* = 56
4. Investigations should be included in lessons as a way to reinforce the scientific concepts students have already learned in class. *T*	1.8	0.6	*N* = 56
5. Lessons should be designed in a way that allows students to learn new concepts through inquiry instead of through a lecture, a reading or a demonstration. *R*	3.3	0.7	*N* = 55
6. During a lesson, students need to be given opportunities to test, debate and challenge ideas with their peers. *R*	3.2	0.5	*N* = 56
7. During a lesson, students should explore and conduct their own investigations with hands-on materials before the teacher discusses any [astronomy] concepts with them. *R*	2.6	0.7	*N* = 54
8. During a lesson, teachers should spend more time asking questions that trigger divergent ways of thinking than they do explaining the concept to students. *R*	3.0	0.5	*N* = 53
Cumulative	2.8	0.5	

The distributions of classifications for *Lesson Design and Implementation* and *Characteristics of Teachers and the Learning Environment* were similar to each other but different than *Nature of the Astronomy Curriculum*. The majority of teachers (59% and 51%, respectively) were reform-oriented and few teachers chose the traditional perspective. And while few teachers were classified as *agreeable*, large fractions were neutral in their responses (25% and 39%, respectively). Neutral response teachers both agreed and disagreed with both the reform and traditional items. Perhaps these teachers have not strongly committed to one perspective. This further supports the above assertion that teachers hold complex belief systems about astronomy teaching resulting in mixed responses on the questionnaire.

A binary logistic regression was used to determine whether any variables significantly predicted the classification of a teacher for each for the three categories. The binary logistic regression is used when the dependent variable, such as being a reform-minded teacher or not, is dichotomous. Thus the analysis was performed for each of the classifications where there was a minimum of twenty subjects in the category. Variables tested as predictors of teacher belief category included district size, middle versus high school teachers, average

Table 6. Characteristics of teachers and the learning environment (the following text originally appeared in Sampson and Benton 2006). T = traditional item; R = reform-based item; scale is from 1 (highly traditional) to 4 (highly reform-based)

	Mean	SD	Total
1. The teacher should motivate students to finish their work as quickly as possible. *T*	2.9	0.6	$N=53$
2. Students should work independently as much as possible so they do not learn to rely on other students to do their work for them. *T*	2.7	0.6	$N=55$
3. An excellent science teacher is someone who is really good at explaining complicated concepts clearly and simply so that everyone understands. *T*	2.0	0.5	$N=55$
4. Students should be willing to accept the scientific ideas and theories presented to them during science class without question. *T*	3.2	0.6	$N=54$
5. Teachers should allow students to help determine the direction and the focus of a lesson. *R*	2.6	0.6	$N=54$
6. In science classrooms, students should be encouraged to challenge ideas while maintaining a climate of respect for what others have to say. *R*	3.4	0.5	$N=56$
7. Science teachers should primarily act as a resource person; working to support and enhance student investigations rather than explaining how things work. *R*	2.9	0.6	$N=54$
8. Students should do most of the talking in science classrooms. *R*	2.7	0.6	$N=52$
Cumulative	2.8	0.4	

percentage of free or reduced lunch (middle or high school), feeling of preparation for teaching, number of standards covered, time per standard, number of astronomy courses, and classification in the other two categories. No predictors were found for whether or not a teacher was reform-minded on *The Nature of the Astronomy Curriculum*. But, whether or not a teacher was classified as reform-minded on *Lesson Design and Implementation* was a significant predictor of whether or not a teacher was classified as reform ($N=56, p<0.01$) or neutral ($N=56, p<0.05$) in the *Characteristics of Teachers and the Learning Environment*. Twenty-three (41%) teachers were categorized as reform on both category 2 (*Lessons*) and category 3 (*Learning Environment*). Fifteen (27%) teachers were classified as reform on both category 1 (*Curriculum*) and category 2 (*Lessons*) while 11 (20%) teachers were classified as reform on both categories 1(*Curriculum*) and 3 (*Learning Environment*).

Table 7. Classification of teacher beliefs

Classification of Teachers' Responses	The Nature of the Astronomy Curriculum ($N=56$)	Lessons Design and Implementation ($N=56$)	Characteristics of Teacher s and the Learning Environment ($N=56$)
Reform	20 (35.7%)	33 (58.9%)	29 (51.8%)
Agreeable	21 (36.2%)	4 (7.1%)	2 (3.6%)
Neutral	5 (8.6%)	14 (25%)	22 (39%)
Contrary	2 (3.6%)	1 (1.8%)	2 (3.6%)
Traditional	8 (13.8%)	4 (7.1%)	1 (1.8%)

Only 10 teachers (18%) were classified as reform-oriented across all three categories.

4. CONCLUSIONS AND FUTURE DIRECTIONS

This study examined the ways in which astronomy is included in the secondary curriculum in Pennsylvania and the beliefs about teaching and learning held by those teachers of astronomy. Our results indicate that we must look across a range of courses to find where astronomy is being taught. The Pennsylvania State Standards cover a broad range of astronomy topics; while all standards are covered across the sample of teachers, the overall picture is one of sporadic coverage (though some topics such as gravity and basic star types seem to be given more weight across the range of teachers and districts). However, if the trends of Pennsylvania hold across most other states, many students have no opportunity to study astronomy in secondary school, and those that do often do so only for one-third or less of the school year in middle or high school. Based on our measure of instructional intensity, we find that the relatively high number of standards being covered in short spans of teaching time may be of some concern. Some of these difficulties may be due to the extensive nature of the standards in Pennsylvania. In the 2002 Pennsylvania Science Standards (Pennsylvania Department of Education 2002), 18 specific statements regarding astronomy were included for grades 7, 10, and 12. In the new Pennsylvania Science, Technology, and Engineering Standards (Pennsylvania Department of Education 2009), 9 statements describe astronomy concepts for middle grades and 12 statements for high school. (However, we note that these standards provide clarity and accuracy that was missing in the 2002 version and there is extensive overlap in the concepts covered by these 21 statements.) Slater, Slater, and Olson (2009) also found that the high number of standards and limited time available was a concern of their "Alpha" teachers. Those teachers expressed a desire to engage their students in inquiry about astronomy but lacked the time to do so. This is likely to be a common problem among all teachers of astronomy. We may conclude that many students are receiving limited astronomy instruction and those teachers that do include astronomy may be squeezing as many topics into a short amount of time as possible. This limits the possibility of the type of extensive mental restructuring of ideas needed to produce conceptual change in learners on the many documented misconceptions about astronomy (Pintrich, Marx, and Boyle 1993; Posner *et al.* 1982; Vosniadou 2003).

A reorganization of the standards with greater focus on developing fewer "big ideas" in science could help teachers give students the necessary depth into fundamental concepts. Recent research and policy documents have proposed that organizing standards and curriculum around these big ideas through the development of *learning progressions* (a description of how children's knowledge of a fundamental idea in science may grow in sophistication across time through targeted instruction) will help minimize extraneous content and allow teachers the time to go into depth in science (e.g., Corcoran, Mosher, and Rogat 2009; Duschl, Schweingruber, and Shouse 2007; Smith *et al.* 2006). Such a reorganization could also free up time and create the appropriate climate for teachers to engage in more inquiry-oriented instruction that promotes depth rather than breadth. However, our survey of teacher beliefs suggests that some teachers may not hold similar philosophies about astronomy education. On average, teachers were neutral on the item asking whether they agree that astronomy curricula should only focus on a few astronomy concepts per semester. The teachers surveyed believe that the curriculum should focus on basic facts and skills that they will need to know later. These findings also have implications for curriculum development. Adoption of reform-based curriculum in an effort to produce change will fail if developers do not consider teachers' existing belief structures (Cronin-Jones 1991).

Teacher classifications in their responses to *The Nature of the Astronomy Curriculum* showed the most diversity. While many were consistently reform-minded, an equal fraction agreed with both reform and traditional items. And a sizeable number of teachers were also consistently traditional in their beliefs about the astronomy curriculum. Teacher classifications in the other two categories, *Lesson Design and Implementation* and *Characteristics of Teachers and the Learning Environment*, suggest that many teachers are reform minded but that a large population is fluctuating in their responses, choosing equally among reform and traditional approaches. While the trend is toward teachers who can be classified as reform-oriented in their pedagogical beliefs, there are still many who do not strongly distinguish between reform practices and traditional practices in astronomy. Of further concern is how teachers view the use of inquiry-based instruction. Responses indicate trends toward a traditional perspective on the use of inquiry in the classroom; many of the teachers believe that investigations should be used to confirm previously learned material and should not be used to introduce a topic. As in previous studies of secondary-science teachers' understanding of the NOS (Brickhouse 1990; Gallagher 1991), these teachers believe that astronomical research is conducted through the use of a single "scientific method."

But how do secondary science teachers' beliefs relate to their actions in the classroom? Teachers' beliefs have been found to be a strong predictor of their use of reform-based practices (Haney, Czerniak, and Lumpe 1996). Simmons *et al.* (1999) conducted a study on the practices and beliefs of first-, second-, and third-year teachers. (The majority of teachers taught science while the rest taught mathematics.) In the second year, the teachers' beliefs begin to conform to the actualities of their classroom practices, becoming more congruent, and becoming more teacher-centered. By their third year of teaching, the teachers' actions more closely reflected their beliefs and reflected more teacher-centered philosophies, but still they often "wobbled" in their beliefs across the categories "interactions in the classroom" and "philosophy of teacher." Such wobbling may be similar to our *neutral* category. The connection between beliefs and practice was greatest in subject content and process. The teachers find ways to "justify their actions" in their teaching, which results in stronger reflection of practice in beliefs. "This personal construction may be incoherent, only partially clear, or not at all free from contradictions. Teachers believed they were student-centered in how they viewed themselves as teachers, but were teacher-centered in their classroom actions, and did not discover or reconcile this inconsistency. We should expect to find teachers holding conflicting and inconsistent beliefs, philosophies, and interpretations of the world" (Simmons *et al.* 1999, pp. 947–948). We conclude that while we may find that some of our teachers of astronomy practice what they believe, it is likely that we will find more teacher-centered, traditional practices if we observed these teachers in the classroom than are reflected in the beliefs professed in the survey, especially among those teachers that were classified as *agreeable* or *neutral*.

Future professional development for teachers of astronomy should be designed to address the combination of both traditional and reform-based beliefs that form many teachers' pedagogical framework. Fortunately, the teachers of astronomy in this study strongly favored future professional development in astronomy, a finding consistent with previous surveys of astronomy teachers (Krumenaker 2009a, 2009b; Slater, Slater, and Olson 2009). Just as we design instruction of students to confront misconceptions, we can use these results to confront misconceptions among astronomy teachers (Haney and McAurthur 2002). Teacher attitudes are of paramount importance in determining whether change will be adopted; thus, professional development must work toward fostering positive attitudes toward reform-minded goals and to help teachers see themselves as change-agents (Haney, Czerniak, and Lumpe 1996). However, changing attitudes and beliefs alone are not enough to produce system-wide change. Moving teachers toward reform-based teaching requires that teachers' beliefs and understandings can be played out in the reality of their teaching context (Anderson 2002; Brickhouse 1990; Simmons *et al.* 1999). School district pressure to cover many concepts or standards in a short period of time may cause teachers altering their classroom strategies to accommodate those demands. These changes tend toward teacher-centered strategies, and over time teachers are likely to accept these accommodations into their belief structures (Simmons *et al.* 1999).

The majority of teachers of astronomy feel that they are prepared to teach astronomy, specifically in the areas that they teach. Most participants have taken at least one college astronomy course, though a large fraction of the teachers have not. Perhaps this level of training is not surprising given the limited emphasis on astronomy concepts in the secondary curriculum. In comparison, Krumenaker (2009a) found that only 15% of teachers who teach a high school astronomy course have not taken astronomy. Teachers are covering astronomy in limited depth over short periods of time. Future research should address the needs of teachers of astronomy in ways that go beyond their own personal feelings of preparedness. We wonder whether or not these teachers are able to recognize limitations to their own preparedness, both in terms of their own content knowledge but also their pedagogical content knowledge in the area of astronomy. While they may be prepared to teach these concepts in limited depth and with few opportunities to participate in inquiry-based instruction, a reform-oriented classroom will require teachers be prepared to have a greater depth of knowledge and understanding of scientific reasoning in the domain.

The results of this survey lead us to suggest several additional areas for further inquiry. While many teachers claim to agree with reform-minded practices, our survey is limited by only accessing their belief system and not their actions. To what extent do these practices appear in teachers' actual teaching? Further investigation should determine what internal (such as teacher beliefs) and external (such as standards and district requirements) limit teachers abilities to enact reform-minded practices. Such investigations could lead to future professional-development strategies that would help shift secondary teachers toward new ways of thinking about their instruction. We also are limited to the extent that we can distinguish between teachers' desires and beliefs about their own practice and the external pressures put in place by school and district mandates. Thus professional development must be combined with coordinated efforts to reform at the district and statewide level to produce meaningful change.

Although we looked across a large number of districts, including suburban, urban, and rural locations, we are somewhat limited in how these findings can be generalized across other states or other countries with different standard documents governing their inclusion of astronomy in the curriculum. However, these findings provide a starting place for future research to extend to new settings and to ask more in depth questions about the coverage of astronomy at the secondary level, teacher preparation and access to resources, and beliefs about teaching astronomy. A further limitation of this study relates to how we measured "coverage" of the standards. Our study gives a general sense of which standards are taught and for how long, but this is based on self-reporting. Two different teachers who state that they cover a specific standard may actually be teaching different content or the same content but to varying degrees of depth. We similarly are limited in our measurement of *instruction intensity*, as this was based on the reported number of standards and a chunked measurement of time spent on astronomy. One advantage of the method used in this study, however, is that it is a relatively easy construct to measure without imposing significantly on individual teacher's time thus, presumably, increasing the number of subjects who completed the survey. However, future research could design more nuanced measurements of instruction intensity to enhance our understanding of the level of depth of astronomy coverage at the secondary level.

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Appendix A – Teacher Survey

A.1. Part I: Introduction

1. Have you taught any courses with astronomy content (either from the list above or any other astronomy concepts) in the recent past (2 years) in your current school? (Yes/no) → If no, then the survey ends here.

We are interested in all of the courses that you teach that include astronomy content. You will have the opportunity to answer questions about each of those courses. Please type the name of the first course below. After you answer questions about that course, you will be prompted to give the names of any other courses. If there are no other courses you will proceed to the next section of the survey.

A.2. Part II: Content of the Astronomy-Related Courses

[The next set of questions was asked for each of the courses listed in questions.]

2. What grade level students are in this course? (Please check all that apply.)
   Fifth, sixth, seventh, eighth, ninth, tenth, eleventh, twelfth
3. Check off all of these standards that you cover in your course (even if you do not fully meet the standard).

[The text of the following standards is copied verbatim from the Pennsylvania state science standards except for the last two bullet points which are one statement on the original document (Pennsylvania Department of Education, 2002). After each bullet point below, participants selected either yes or no.]

3.4.7 Physical Science, Chemistry and Physics

D. Describe essential ideas about the composition and structure of the universe and the earth's place in it.

- Compare various planets' characteristics.
- Describe basic star types and identify the sun as a star type.
- Describe and differentiate comets, asteroids and meteors.
- Identify gravity as the force that keeps planets in orbit around the sun and governs the rest of the movement of the solar system and the universe.
- Illustrate how the positions of stars and constellations change in relation to the Earth during an evening and from month to month.
- Identify equipment and instruments that explore the universe.

- Identify the accomplishments and contributions provided by selected past and present scientists in the field of astronomy.
- Identify and articulate space program efforts to investigate possibilities of living in space and on other planets.

3.4.10 Physical Science, Chemistry and Physics

D. Explain essential ideas about the composition and structure of the universe.

- Compare the basic structures of the universe (e.g., galaxy types, nova, black holes, neutron stars).
- Describe the structure and life cycle of star, using the Hertzsprung-Russell diagram.
- Describe the nuclear processes involved in energy production in a star.
- Explain the “red-shift” and Hubble’s use of it to determine stellar distance and movement.
- Compare absolute versus apparent star magnitude and their relation to stellar distance.
- Explain the impact of the Copernican and Newtonian thinking on man’s view of the universe.
- Identify and analyze the findings of several space instruments in regard to the extent and composition of the solar system and universe.

3.4.12 Physical Science, Chemistry and Physics

D. Analyze the essential ideas about the composition and structure of the universe.

- Analyze the Big Bang Theory’s use of gravitation and nuclear reaction to explain a possible origin of the universe.
- Compare the use of visual, radio and x-ray telescopes to collect data regarding the structure and evolution of the universe.
- Explain the special theory of relativity
- Describe the life cycle of a star.

4. Describe any additional astronomy concepts that you address in your course.
5. How long do you spend on astronomy concepts in this course?
   Less than 1 week, 1–2 weeks, 2 weeks – a month, 1–2 months, more than 2 months
6. How many sections of this course do you teach each year? [comment box]
7. On average, how many students are in each of your sections of this class?
8. Have you taught any other courses with astronomy content in the past 2 years? [yes/no]

A.3. Part III: Preparation and Resources for Astronomy Teaching

9. What resources do you have available for teaching astronomy? (list possibilities with yes, sometimes, no and leave the option open for comments):
   a. Access to astronomy websites
   b. Access to astronomy software
   c. Models of astronomical objects
   d. The students’ textbook
   e. Astronomy-related books other than the textbook
   f. Telescope(s)
   g. Planetarium (including fieldtrips)
   h. A curriculum that includes astronomy activities and projects
   i. Other (describe below or give more details in the comment box)

10. Which of the previous resources do you use when teaching astronomy? (Describe)
11. Do you feel prepared to teach astronomy? (Strongly Agree, Agree, Disagree, Strongly Disagree)
12. Have you taken any college-level courses with astronomy content? (Please list the names or short descriptions of the courses)
13. Describe any astronomy-focused professional development in which you have participated.
14. Describe the aspects of astronomy that you feel confident teaching
15. Are there aspects of astronomy that you feel less confident in teaching?
16. If there were opportunities for additional professional development in astronomy would you be interested in participating? Strongly Agree, Agree, Disagree, Strongly Disagree

A.4. Part IV: Science Teaching and Learning Beliefs

(This portion was adapted from Sampson and Benton (2006).)

The Nature of the Science Curriculum

The following statements describe different things that students can learn about **astronomy** while in school. Based on your opinion of what students should learn about during their science classes, indicate if you agree or disagree.

	SD	D	A	SA
1. A good astronomy curriculum should focus on only a few astronomy concepts a semester, but in great detail.	1	2	3	4
2. The astronomy curriculum should focus on the basic facts and skills of astronomy that students will need to know later.	1	2	3	4
3. Students should know that astronomical knowledge is discovered using the scientific method.	1	2	3	4
4. The astronomy curriculum should encourage students to learn and value alternative modes of investigation or problem solving.	1	2	3	4
5. In order to prepare students for future classes, college, or a career in science the science curriculum should cover as many different topics as possible over the course of a school year.	1	2	3	4
6. The astronomy curriculum should help students develop the reasoning skills and habits of mind necessary to do science.	1	2	3	4
7. Students should learn that all science is based on a single scientific method—a step-by-step procedure that begins with 'define the problem' and ends with 'reporting the results.'	1	2	3	4
8. A good science curriculum should focus on the history and NOS and how science affects people and societies.	1	2	3	4

Lesson Design and Implementation

The statements below describe different ways **astronomy lessons** can be designed and taught in school. Based on your opinion of how science should be taught, indicate if you agree or disagree.

	SD	D	A	SA
9. Assessments in science classes should only be given after instruction is completed; that way the teacher can determine if the students have learned the material covered in class.	1	2	3	4
10. During a lesson, teachers should spend more time asking questions that trigger divergent ways of thinking than they do explaining the concept to students.	1	2	3	4

	SD	D	A	SA
11. During a lesson, students need to be given opportunities to test, debate and challenge ideas with their peers.	1	2	3	4
12. Investigations should be included in lessons as a way to reinforce the scientific concepts students have already learned in class.	1	2	3	4
13. Lessons should be designed in a way that allows students to learn new concepts through inquiry instead of through a lecture, a reading or a demonstration.	1	2	3	4
14. Whenever students conduct an investigation during an astronomy lesson, the teacher should give step-by-step instructions for the students to follow in order to prevent confusion and to make sure students get the correct results.	1	2	3	4
15. During a lesson, all of the students in the class should be encouraged to use the same approach for conducting an investigation or solving a problem.	1	2	3	4

Characteristics of Teachers and the Learning Environment

The statements below describe different characteristics of teachers and classroom learning environments. Based on your opinion of what a good science teacher is like and what a classroom should be like, indicate if you agree or disagree.

	SD	D	A	SA
16. Students should do most of the talking in science classrooms.	1	2	3	4
17. Students should work independently as much as possible so they do not learn to rely on other students to do their work for them.	1	2	3	4
18. In science classrooms, students should be encouraged to challenge ideas while maintaining a climate of respect for what others have to say.	1	2	3	4
19. Teachers should allow students to help determine the direction and the focus of a lesson.	1	2	3	4
20. Students should be willing to accept the scientific ideas and theories presented to them during science class without question.	1	2	3	4
21. An excellent science teacher is someone who is really good at explaining complicated concepts clearly and simply so that everyone understands.	1	2	3	4
22. The teacher should motivate students to finish their work as quickly as possible.	1	2	3	4

Appendix B – Administrator Interview

As part of the Math and Science Partnership of Greater Philadelphia research agenda, I am interested in discussing how astronomy is included in your school/district.

1. In which courses are astronomy standards met in your middle school/high school curriculum?
   For each course:
   a. Is this a required course?
   b. If not, how many students take this course?
   c. What grade level students take this course?
   d. Can you provide a brief description of which astronomy concepts are covered in this course?
   e. Is there a standard textbook for this course?
   f. Is there a curriculum document for this course, so that I can have a record of the standards and objectives for this course?
2. What district level resources are available for your teachers? (planetarium, telescope(s), astronomy software, models, curricula, etc.)

Appendix C – Coverage Of Pennsylvania State Astronomy Standards Across Middle And High School: Course By Course Analysis

Standard description	Standard #	Percentage of total (N=72)[a]	High School (N=32)	Middle School (N=37)	9th Grade only (N=2)
Compare various planets' characteristics.	3.4.7 D.1	41 (57%)	15 (47%)	24 (65%)	2 (100%)
Describe basic star types and identify the sun as a star type.	3.4.7 D.2	45 (63%)	19 (59%)	24 (65%)	2 (100%)
Describe and differentiate comets, asteroids and meteors.	3.4.7 D.3	40 (56%)	14 (44%)	24 (65%)	2 (100%)
Identify gravity as the force that keeps planets in orbit around the sun and governs the rest of the movement of the solar system and the universe.	3.4.7 D.4	62 (86%)	27 (84%)	32 (86%)	2 (100%)
Illustrate how the positions of stars and constellations change in relation to the Earth during an evening and from month to month.	3.4.7 D.5	34 (47%)	12 (38%)	19 (51%)	2 (100%)
Identify equipment and instruments that explore the universe.	3.4.7 D.6	45 (63%)	16 (50%)	26 (70%)	2 (100%)
Identify the accomplishments and contributions provided by selected past and present scientists in the field of astronomy.	3.4.7 D.7	39 (54%)	13 (41%)	23 (62%)	2 (100%)

Standard description	Standard #	Percentage of total (N=72)[a]	High School (N=32)	Middle School (N=37)	9th Grade only (N=2)
Identify and articulate space program efforts to investigate possibilities of living in space and on other planets.	3.4.7 D.8	27 (38%)	12 (38%)	15 (41%)	1 (50%)
Compare the basic structures of the universe (e.g., galaxy types, nova, black holes, neutron stars).	3.4.10 D.1	35 (49%)	14 (44%)	18 (49%)	2 (100%)
Describe the structure and life cycle of star, using the Hertzsprung-Russell diagram.	3.4.10 D.2	35 (49%)	14 (44%)	18 (49%)	2 (100%)
Describe the nuclear processes involved in energy production in a star.	3.4.10 D.3	41 (57%)	19 (59%)	19 (51%)	2 (100%)
Explain the "red-shift" and Hubble's use of it to determine stellar distance and movement.	3.4.10 D.4	30 (42%)	14 (44%)	13 (35%)	2 (100%)
Compare absolute versus apparent star magnitude and their relation to stellar distance.	3.4.10 D.5	26 (36%)	9 (28%)	14 (38%)	2 (100%)
Explain the impact of the Copernican and Newtonian thinking on man's view of the universe.	3.4.10 D.6	33 (46%)	14 (44%)	16 (43%)	2 (100%)
Identify and analyze the findings of several space instruments in regard to the extent and composition of the solar system and universe.	3.4.10 D.7	25 (35%)	8 (25%)	17 (46%)	0
Analyze the Big Bang Theory's use of gravitation and nuclear reaction to explain a possible origin of the universe.	3.4.12 D.1	33 (44%)	16 (50%)	13 (35%)	2 (100%)
Compare the use of visual, radio and x-ray telescopes to collect data regarding the structure and evolution of the universe.	3.4.12 D.2	20 (28%)	7 (22%)	12 (32%)	1 (50%)
Explain the special theory of relativity.	3.4.12 D.3.1	14 (19%)	7 (22%)	4 (11%)	2 (100%)
Describe the life cycle of a star.	3.4.12 D.3.2	42 (58%)	17 (53%)	22 (59%)	2 (100%)

Standard description	Standard #	Percentage of total ($N=72$)[a]	High School ($N=32$)	Middle School ($N=37$)	9th Grade only ($N=2$)
Other concepts mentioned not in secondary standards					
Lunar concepts		5 (7%)	0	4 (11%)	1 (50%)
Sun-Earth-Moon system		4 (6%)	0	3 (8%)	1 (50%)
Spectral Analysis		4 (6%)	1 (3%)	1 (3%)	1 (50%)
Seasons		2 (3%)	0	2 (5%)	0

[a]One participant did not specify the grade level. These responses are included in the total but not the individual columns for middle school, high school, or 9th grade only.

Appendix D – Coverage Of Pennsylvania State Astronomy Standards In Required And Elective Courses Across All Districts ($N=24$)

Standard description	Standard #	Required courses-surveyed districts ($N=9$)	Required plus elective courses-surveyed districts ($N=9$)	Required plus elective courses in all districts ($N=24$)
Compare various planets' characteristics.	3.4.7 D.1	6	8	22 (92%)
Describe basic star types and identify the sun as a star type.	3.4.7 D.2	3	4	18 (75%)
Describe and differentiate comets, asteroids and meteors.	3.4.7 D.3	6	7	21 (88%)
Identify gravity as the force that keeps planets in orbit around the sun and governs the rest of the movement of the solar system and the universe.	3.4.7 D.4	5	5	20 (83%)
Illustrate how the positions of stars and constellations change in relation to the Earth during an evening and from month to month.	3.4.7 D.5	1	1	14 (58%)
Identify equipment and instruments that explore the universe.	3.4.7 D.6	4	5	18 (75%)
Identify the accomplishments and contributions provided by selected past and present scientists in the field of astronomy.	3.4.7 D.7	2	3	13 (54%)
Identify and articulate space program efforts to investigate possibilities of living in space and on other planets.	3.4.7 D.8	3	3	15 (63%)
Compare the basic structures of the universe (e.g., galaxy types, nova, black holes, neutron stars).	3.4.10 D.1	3	4	17 (71%)
Describe the structure and life cycle of star, using the Hertzsprung-Russell diagram.	3.4.10 D.2	2	4	17 (71%)
Describe the nuclear processes involved in energy production in a star.	3.4.10 D.3	0	0	11 (46%)
Explain the "red-shift" and Hubble's use of it to determine stellar distance and movement.	3.4.10 D.4	0	0	12 (50%)
Compare absolute versus apparent star magnitude and their relation to stellar distance.	3.4.10 D.5	0	0	12 (50%)

Standard description	Standard #	Required courses-surveyed districts ($N=9$)	Required plus elective courses-surveyed districts ($N=9$)	Required plus elective courses in all districts ($N=24$)
Explain the impact of the Copernican and Newtonian thinking on man's view of the universe.	3.4.10 D.6	0	0	9 (38%)
Identify and analyze the findings of several space instruments in regard to the extent and composition of the solar system and universe.	3.4.10 D.7	1	1	10 (42%)
Analyze the Big Bang Theory's use of gravitation and nuclear reaction to explain a possible origin of the universe.	3.4.12 D.1	2	3	15 (63%)
Compare the use of visual, radio and x-ray telescopes to collect data regarding the structure and evolution of the universe.	3.4.12 D.2	0	1	12 (50%)
Explain the special theory of relativity.	3.4.12 D.3.1	0	1	6 (25%)
Describe the life cycle of a star.	3.4.12 D.3.2			13 (54%)
Other concepts not mentioned in secondary standards				
Lunar concepts		3	5	5 (21%)
Sun-Earth-Moon system		6	7	8 (33%)
Spectral Analysis		0	0	2 (8%)
Seasons		2	1	3 (13%)

References

Abd-El-Khalick, F., and Lederman, N. 2000, "Improving Science Teachers' Conceptions of Nature of Science: A Critical Review of the Literature," *International Journal of Science Education*, 22, 665.

Abell, S., Martini, M., and George, M. 2001, "That's What Scientists Have to Do': Preservice Elementary Teachers' Conceptions of the Nature of Science During a Moon Investigation," *International Journal of Science Education*, 23, 1095.

Akerson, V. L. 2005, "How Do Elementary Teachers Compensate for Incomplete Science Content Knowledge?" *Research in Science Education*, 35, 245.

Akerson, V. L., Hanson, D. L., and Cullen, T. A. 2007, "The Influence of Guided Inquiry and Explicit Instruction on K-6 Teachers' Views of Nature of Science," *Journal of Science Teacher Education*, 18, 751.

American Association for the Advancement of Science 1993, *Benchmarks for Science Literacy*, New York: Oxford University Press.

Anderson, R. D. 2002, "Reforming Science Teaching: What Research Says about Inquiry," *Journal of Science Teacher Education*, 13, 1.

Atwood, R. K., and Atwood, V. A. 1996, "Preservice Elementary Teachers' Conceptions of the Causes of Seasons," *Journal of Research in Science Teaching*, 33, 553.

Atwood, V. A., and Atwood, R. K. 1995, "Preservice Elementary Teachers' Conceptions of What Causes Night and Day," *School Science and Mathematics*, 95, 290.

Bishop, J. E. 1990, in *The Teaching of Astronomy*, ed. J. M. Pasachoff, and J. R. Percy, Cambridge: Cambridge University Press, 259.

Brickhouse, N. W. 1990, “Teachers’ Beliefs about the Nature of Science and their Relationship to Classroom Practice,” *Journal of Teacher Education*, 41, 53.

Brunsell, E., and Marcks, J. 2004, “Identifying a Baseline for Teachers’ Astronomy Content Knowledge,” *Astronomy Education Review*, 3, 38.

Corcoran, T., Mosher, F. A., and Rogat, A. 2009, *Learning Progressions in Science: An Evidence-Based Approach to Reform (Consortium for Policy Research in Education report)*, Philadelphia, Pennsylvania: Consortium for Policy Research in Education.

Cronin-Jones, L. L. 1991, “Science Teacher Beliefs and their Influence on Curriculum Implementation: Two Case Studies,” *Journal of Research in Science Teaching*, 28, 235.

Duschl, R., Schweingruber, H., and Shouse, H. 2007, *Taking Science to School*, Washington D. C.: National Academy Press.

Gallagher, J. J. 1991, “Prospective and Practicing Secondary School Science Teachers’ Knowledge and Beliefs about the Philosophy of Science,” *Science Education*, 75, 121.

GreatSchools, Inc. 2008. “Public and Private School Ratings, Reviews and Parent Community,” http://wwww.greatschools.net.

Hammrich, P. L. 1998, “What the Science Standards say: Implications for Teacher Education,” *Journal of Science Teacher Education*, 9, 165.

Haney, J. J., Czerniak, C. M., and Lumpe, A. T. 1996, “Teacher Beliefs and Intentions Regarding the Intentions Regarding the Implementation of Science Education Reform Strands,” *Journal of Research in Science Teaching*, 33, 971.

Haney, J. J., and McAurthur, J. 2002, “Four Case Studies of Prospective Science Teachers’ Beliefs Concerning Constructivist Teaching Practices,” *Science Education*, 86, 783.

Krumenaker, L. 2009a, “The Modern U.S. High School Astronomy Course, its Status and Makeup, and the Effects of No Child Left Behind,” *Astronomy Education Review*, 8.

Krumenaker, L. 2009b, “The Modern U.S. High School Astronomy Course, its Status and Makeup II: Additional Results,” *Astronomy Education Review*, 8.

Lederman, N. 1992, “Students’ and Teachers’ Concepts of Nature of Science: A Review of the Research,” *Journal of Research in Science Teaching*, 29, 331.

Marbach-Ad, G., and McGinnis, J. R. 2008, “To What Extent Do Reform-Prepared Upper Elementary and Middle School Science Teachers Maintain their Beliefs and Intended Instructional Actions as they are Inducted into Schools?” *Journal of Science Teacher Education*, 19, 157.

National Center for Education Statistics 2009. “Search for Public School Districts,” http://nces.ed.gov/CCD/districtsearch.

National Research Council 1996, *National Science Education Standards*, Washington, D.C.: National Academy Press.

National Research Council 2000, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*, Washington, D.C.: National Academy Press.

Pennsylvania Department of Education 2002. “Academic Standards for Science and Technology Education,” http://www.pde.state.pa.us/stateboard_ed/cwp/view.asp?Q=76716.

Pennsylvania Department of Education 2009. “Academic Standards for Science and Technology and Engineering Education,” http://www.portal.state.pa.us.

Pintrich, P. R., Marx, R., and Boyle, R. 1993, “Beyond Cold Conceptual Change: The role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change,” *Review of Educational*

Research, 63, 167.

Plummer, J. D., Zahm, V., and Rice, R. 2010, “Inquiry and Astronomy: Preservice Teachers’ Investigations of Celestial Motion,” *Journal of Science Teacher Education*, 21, 471.

Posner, G. J., Strike, K. A., Hewson, P. W., and Gertzog, W. A. 1982, “Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change,” *Science Education*, 66, 211.

Roehrig, G. H., and Kruse, R. A. 2005, “The Role of Teachers’ Beliefs and Knowledge in the Adoption of a Reform-Based Curriculum,” *School Science and Mathematics*, 105, 412.

Sadler, P. M. 1992, “High School Astronomy: Characteristics and Student Learning,” in *Proceedings of the Workshop on Hands-On Astronomy for Education*, ed. E. Carlton Pennypacker, Singapore: World Scientific.

Sadler, P. M. 1998, “Psychometric Models of Student Conceptions in Science: Reconciling Qualitative Studies and Distractor-Driven Assessment Instruments,” *Journal of Research in Science Teaching*, 35, 265.

Sampson, V., and Benton, A. 2006 “Development and Validation of the Beliefs About Reformed Science Teaching and Learning (BARSTL) questionnaire,” Paper presented at the Annual Conference of the Association of Science Teacher Education (ASTE). Portland, Oregon. Retrieved February 16, 2008, from http://ret.fsu.edu/Research_Tools.htm.

Schwartz, M. S., Sadler, P. M., Sonnert, G., and Tai, R. H. 2009, “Depth Versus Breadth: How Content Coverage in High School Science Courses Relates To Later Success in College Science Coursework,” *Science Education*, 93, 798.

Simmons, P. E., Emory, A., Carter, T., Coker, T., Finnegan, B., Crockett, D., Richardson, L., Yager, R., Craven, J., Tillotson, J., Brunkhorst, H., Twiest, M., Hossain, K., Gallagher, J., Parker, J., Cajas, F., Alshannag, Q., McGlamery, S., Krockover, J., Adams, P., Spector, B., LaPorta, T., James, B., Rearden, K., and Labuda, K. 1999, “Beginning Teachers: Beliefs and Classroom Actions,” *Journal of Research in Science Teaching*, 36, 930.

Slater, S. J., Slater, T. F., and Olson, J. K. 2009, “Survey of K-12 Science Teachers’ Educational Product Needs from Planetary Scientists,” *Astronomy Education Review*, 8.

Smith, C. L., Wiser, M., Anderson, C. W., and Krajcik, J. 2006, “Implications of Research on Children’s Learning for Standards and Assessment: A Proposed Learning Progression for Matter and the Atomic Molecular Theory,” *Measurement: Interdisciplinary Research and Perspectives*, 4, 1.

Tobin, K., and McRobbie, C. J. 1996, “Cultural Myths as Constraints to the Enacted Science Curriculum,” *Science Education*, 80, 223.

Trundle, K., Atwood, R., and Christopher, J. 2002, “Preservice Elementary Teachers’ Conceptions of Moon Phases Before and After Instruction,” *Journal of Research in Science Teaching*, 39, 633.

Vosniadou, S. 2003, “Exploring the Relationships Between Conceptual Change and International Learning,” in *International Conceptual Change*, ed. P. R. Pintrich, and G. M. Sinatra, Mahwah, New Jersey: Lawrence Erlbaum Associates, 377.

Vosniadou, S., and Brewer, W. F. 1992, “Mental Models of the Earth: A Study of Conceptual Change in Childhood,” *Cognitive Psychology*, 24, 535.

Vosniadou, S., and Brewer, W. F. 1994, “Mental Models of the Day/Night Cycle,” *Cognitive Science*, 18, 123.

Wallace, C. S., and Kang, N.-H. 2004, “An Investigation of Experienced Secondary Science Teachers’ Beliefs About Inquiry: An Examination of Competing Belief Sets,” *Journal of Research in Science Teaching*, 41, 936.

Zeilik, M., and Bisard, W. 2000, “Conceptual Change in Introductory-Level Astronomy Courses: Tracking Misconceptions to Reveal Which–And How Much–Concepts Change,” *Journal of College Science Teaching*, 29, 229.

Zeilik, M., and Morris, V. 2003, "An Examination of Misconceptions in an Astronomy Course for Science, Mathematics, and Engineering Majors," *Astronomy Education Review*, 2, 101.