A Review of Astronomy Education Research

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Abstract

The field of astronomy education is rapidly growing beyond merely sharing effective activities or curriculum ideas. This paper categorizes and summarizes the literature in astronomy education research and contains more than 100 references to articles, books, and Web-based materials. Research into student understanding on a variety of topics now occupies a large part of the literature. Topics include the shape of Earth and gravity, lunar phases, seasons, astrobiology, and cosmology. The effectiveness of instructional methods is now being tested systematically, taking data beyond the anecdotal with powerful research designs and statistical analyses. Quantitative, qualitative, and mixed- methods approaches have found their places in the researcher's toolbox. In all cases, the connection between the research performed and its effect on classroom instruction is largely lacking.

Astronomy is one of the oldest sciences known. Whether it is the basis of planning for an elaborate religious ceremony or working on the cutting-edge of science and technology, astronomy remains at the forefront of the public's attention and interest. Astronomy in educational contexts—its presence in the classroom, museum, or observatory at any level—has fluctuated with popular opinion of the time. At one time, astronomy was a required course for anyone seeking a college degree; today, most college students see it as only one of many electives at select universities. But in spite of astronomy's long presence in the public eye, research in astronomy education is a very new field. What little systematic research has been conducted on the teaching and learning of astronomy is scattered among many journals over the years. Prior to 2002, there were no journals dedicated to this emerging field; the online journal the *Astronomy Education Review* began publication in late 2001.

As the field of astronomy education research (hereafter AER) grows—and it is doing so vigorously—many readers may find it useful to have a concise summary of what has been published to date. The purpose of this article is to summarize and categorize the various research projects in astronomy education to set the stage for subsequent efforts. In order to limit the extent of this diverse field, we have made purposeful choices about the references included here. In this paper, *research* is defined as those studies that attempt to systematically analyze issues such as student conceptions on a topic or the effectiveness of a particular instructional or curricular intervention. Outside of this definition and the scope of this paper lies a multitude of additional works, including descriptions of innovative activities, curricula, or instructional techniques; information regarding the National Research Council's National Science Education Standards (NRC 1996, hereafter NSES); and articles on the teaching of the nature of science.

The field of astronomy education, both within and outside of this definition of research, has grown tremendously in recent years. This review article is intended to be of use to active astronomy education researchers, scientists, and educators who need to build an understanding of the field's history. Other sources of information in this field include the SABER astronomy Web site (Brissenden 2001), a searchable online database that provides annotated references about learning difficulties and instructional issues, and an extensive Web-based bibliography hosted by the Astronomical Society of the Pacific (Fraknoi 1998).

1. EARLY REPORTS ON ASTRONOMY EDUCATION

One of the earliest summaries of efforts in astronomy education was written by Charles Wall (1973). Wall reviewed science education studies from the period 1922–1972. His report identifies 58 studies in astronomy education, 54 of which were doctoral or master's studies. Wall divides his selected studies into categories of elementary (21 studies), secondary (19), or college level (18). He goes on to further subdivide the works into status articles that describe the condition of astronomy education (12 studies across the three grade categories), achievement (31), or curriculum development (15). Of these studies, only a handful of the elementary-level achievement studies would fall under a contemporary "astronomy education research" category as defined and described above. These studies include those about students' conceptions of the Moon (Haupt 1948; 1950) and of the day/night cycle and gravity (Yuckenberg, as cited in Wall). In contrast to the cognitive focus of AER today, Wall made several recommendations for further study aimed at measuring the effectiveness of audio-visual materials, laboratory equipment, and individualized instruction strategies. Reflective of educational studies of the time, Wall does not recommend additional study to deeply probe student understanding in specific astronomy content areas. This is a historical mirror to how school effectiveness was measured by counting the number of books in the library and square footage of instructional space rather than directly sampling student learning and achievement.

A second seminal chronicle is "United States Astronomy Education: Past, Present, and Future," in which Jeanne Bishop (1977) provides an overview of the field, including changing classroom demographics over time, curriculum development, and the "state of astronomy knowledge," which refers to the attitudes and prevalent ideas held by the public. The need for more and better curriculum materials and teacher enhancement workshops was seen by Bishop as the highest priority and therefore the most strongly recommended. She states, "It seems essential that experienced astronomy teachers and astronomers should work together, with equal responsibility, to develop accurate, up-to-date, but practical and interesting readings and activities. Neither of these groups can develop effective programs alone" (p. 303). This perspective seems as relevant today as it did a quarter-century ago, and guides much of the major contemporary curriculum development efforts described elsewhere (Fraknoi 1998).

1.1 The Other Stuff

A number of other examples in the literature might be classified by Wall (1973) as status pieces. For instance, Janke & Pella (1972) describe the development of a list of 52 topics of importance in Earth science, including 13 that relate directly to astronomy. Yost's 1973 article compares the astronomy portions of fourth- through sixth-grade textbooks and shows similarities and differences between them based on behavioral objectives.

More recently, Adams & Slater (2000) discuss the presence of astronomy topics in the NSES and a give brief overview of related research results. Because of the emphasis on conceptual understanding and teacher education in the standards, the authors call for future research in student understanding and in the development of research-based, concept-specific assessment tools. Morrow (2003) describes seven common misconceptions that scientists have about the NSES, which were encountered during a number of educational activities. Among them were annual workshops for scientists on K–12 education sponsored by the Space Science Institute. *Project 2061*, the science education reform document produced by the American Association for the Advancement of Science (1993), also incorporates a number of astronomy topics in its benchmarks (Slater 2000). Fraknoi (2002) summarizes data from the American Institute of Physics regarding the student composition in introductory astronomy courses. Slater et al. (2001) describe the most common goals and topics taught in these same courses. This information was collected from a survey of astronomy instructors and an analysis of course syllabi available on the Internet.

2. RESEARCH STUDIES ON STUDENT UNDERSTANDING IN ASTRONOMY

The idea that astronomy students actively synthesize and interpret information and experiences into conceptual models that may or may not be scientifically accurate is rooted in the constructivist movement (Slater 1993). This student model-building paradigm has motivated and guided the nature and emphasis of a variety of investigations into student understanding. Certainly the most well-known study of understanding in astronomy was publicized by Philip Sadler and is presented in the video *A Private Universe* (Schneps 1989). The video begins with clips of interviews with several alumni, faculty, and graduating seniors from Harvard University. Of the 23 individuals interviewed, 21 could not give a scientifically acceptable explanation for the cause of the seasons or the phases of the Moon. An explanation for the cause of the seasons that is consistent with a scientifically accurate viewpoint would involve how the amount of sunlight reaching Earth's surface at different latitudes is related to the planet's tilt. However, the most common alternative explanation given was the changing distance between the Sun and Earth (that Earth is closer to the Sun in the summer and farther in the winter). A scientifically accurate description of the lunar phases would explain that, despite half of the Moon being illuminated by the Sun at all times, the portion of that half that can be seen from Earth—what we call the phase—depends upon the relative positions of the Sun, Earth, and Moon. Responders most often incorrectly explained lunar phases by an "eclipse" or "interference" model, where shadows are cast by Earth onto the Moon or clouds block some of the light. In addition to members of the targeted Harvard community, local ninth-grade students were interviewed about these same concepts. The video shows lengthy portions of one student's interview and related commentary by her teacher. Heather, the student, gave detailed explanations and illustrations of her ideas about these concepts. Although she often used terminology that would imply complete understanding, further probing through an interview showed that this was not the case. Heather had deeply held alternative conceptions before instruction, and after instruction, integrated newly learned information into these incorrect ideas in complex and subtle ways.

Although the ideas so clearly illustrated by *A Private Universe* were garnered through methods that probably do not conform to the rules of reliability and validity that define educational research, the video's influence cannot be understated. Modeled after this presentation, similar videos exposing the robustness of students' individual ideas about the natural world have been created and distributed in the areas of simple electric circuits, photosynthesis, and geometric optics. These videos are widely used to help teachers and faculty understand the nature of learning.

Not nearly as well known but more reflective of quantitative research on student understanding is a multiple-choice instrument developed by Sadler (1992) as part of his dissertation work. This instrument addresses misconceptions culled from the literature and his interviews with students. Sadler administered the instrument to over 1,400 high school students and found a mean student score of 34% correct. In fact, Sadler found that many misconceptions (19 of 51) were actually preferred by students over the scientifically accurate concepts.

In addition to motivating much of the current effort in astronomy teaching and AER, a particular strength of Sadler's work is that it lead to the development of the Project STAR curriculum materials (Gregory, Luzader, & Coyle 1995), initiated the widespread use of an inflatable and portable planetarium (STARLAB), and served as the foundation for much of the activities of Project SPICA (Ball, Coyle, & Shapiro 1994). Unfortunately, these efforts did not result in the anticipated substantial improvement in student achievement due to numerous factors, and pretest/posttest evaluation studies were not widely published. Nevertheless, Sadler's efforts directly influence and motivate much of the work published today.

2.1 What Happened to the Moon? (Studies about Lunar Phases)

The prevalence and tenacity of alternative conceptions (see Wandersee, Mintzes, & Novak 1994 for an extensive discussion on this topic) demonstrated by *A Private Universe* are not limited to Sadler's work. For example, Stahly, Krockover, & Shepardson (1999) furthered research on student understanding of the changing lunar phases. In their review of the literature, the authors report that previous studies had been mainly quantitative in nature (using questionnaires or multiple-choice surveys), and thus they adopted a qualitative case study approach and interviewed four US third-grade students. Additional data were collected in the form of written tasks, classroom observation, and teacher feedback. Comparisons between pre- and postinstruction interviews demonstrated that the students showed a positive conceptual change over an instructional intervention characterized as a three-week multiple-component lesson using three-dimensional models, with postinstructional explanations showing more details and more scientifically accurate ideas.

For older students, Lindell (2001) developed the Lunar Phases Concept Inventory (LPCI) from interviews with undergraduate students to measure conceptual change in their understanding of the Moon's phases. Her pretest results confirmed earlier work with younger students and argued that scientifically inaccurate ideas persist into college. The LPCI, a multiple-choice instrument that can be quantitatively analyzed, was used to evaluate the effectiveness of an in-class group activity designed to address these concepts using a constructivist approach. The activity showed statistical success in the way of an unusually large average gain ($g = 0.63$), where *gain* is defined as the ratio of the student's actual increased score to the greatest possible increased score. Lindell & Olsen (2002) describe further revision, field testing, and statistical analysis of the LPCI. More recently, brief Socratic-based tutorial activities (Adams, Prather, & Slater 2002) resulted in even larger gains when coupled with interactive lecture techniques (Slater et al. 2003, March).

Fanetti (2001) interviewed 50 college students and administered an open-ended survey to more than 700 students to investigate their understanding of lunar phases. Her main conclusion from these data is that a lack of understanding of the Moon–Earth system's scale is the main reason for student difficulties in understanding the phases of the Moon. Earlier work by Callison & Wright (1993) investigated the use of different three-dimensional models to teach about lunar phases, focusing especially on the interaction of student spatial ability and reasoning levels in their ability to develop mental models. Barnett & Morran (2002) investigated the use of a project-based curriculum from the Challenger Center (http://www.challenger.org) in a fifth-grade classroom to teach about the phases of the Moon and eclipses. They incorporated findings from research into student understanding by the sequencing of projects, with the report focusing only on the final two projects (covering the relative Earth-Moon-Sun positions and eclipses). Students had opportunities to research information about the orbital motions of the Moon and Earth, as well as to explore an interactive computer model that displayed the Earth-Moon-Sun system from different three-dimensional perspectives. The researchers found that their students were able to increase their understanding of Moon phases (as defined by having a more scientifically complete understanding) after experiencing this series of lessons.

Additional studies about teacher understanding of lunar phases and the effectiveness of inquiry teaching methods on this topic are further described below.

2.2 A Flat Earth? (Studies on the Shape of Earth and Related Issues)

Joseph Nussbaum and his colleagues conducted some of the earliest studies into student conceptual understanding in Earth and space sciences. Nussbaum & Novak (1976) used semistructured clinical interviews to uncover student conceptions about the shape of Earth, its position in space, and how gravity affects falling objects. From interviews with second-grade students, the researchers discovered five recurring "notions" describing the shape of Earth—only one of which is scientifically accurate—despite many student comments that on the surface appear to be correct. These notions included: (a) the flat but round (like a pancake) Earth, with no concept of "space"; (b) a spherical Earth but with an external ground that "limits" things that fall, defining an absolute down (as if the ball-shaped Earth were separate from the everyday ground the student experiences); (c) a spherical Earth with some idea of unlimited space but maintaining an absolute down concept (where things on the "bottom" of Earth might fall off); (d) a spherical Earth with space around it, but persistent problems with falling objects; and (e) a spherical Earth surrounded by space, with gravity pulling objects toward the center of the planet (scientifically accurate). Illustrations of these notions can be seen in Nussbaum & Novak.

Nussbaum (1979) expanded this work in an attempt to generalize the earlier results on Earth-shape notions. The interview format was adapted into a multiple-choice instrument with additional space to allow students to provide explanations or drawings; the children also were provided with three-dimensional models to manipulate during their explanations. A total of 240 Israeli students in grades four through eight were interviewed and their notions categorized. The number of children with scientifically accurate models increased somewhat with age, providing indirect support for the idea that a developmental trend exists. Using the same methods as the Nussbaum & Novak (1976) study, Mali & Howe (1979) looked at the cognitive development of Nepali children. Somewhat surprisingly, they also found all five of the Nussbaum & Novak notions to be present in this very different population, leading to the idea that the notions are not culturally engendered. Mali & Howe also found a slight progression toward more advanced notions with age, although the notion/age relationship tended to be systematically shifted relative to the results of the American studies. Nussbaum & Sharoni-Dagan (1983) further addressed alternative conceptions in a study of the effectiveness of audio-tutorials, where, contrary to popular belief, they found that younger children were able to seemingly grasp the abstract notions of Earth as a cosmic body when presented with appropriately targeted instruction.

Klein (1982) addressed similar issues of student understanding in a cultural comparison of Mexican American and Anglo American second-grade students. She found that students held a number of ideas contrary to concepts they had been exposed to in the classroom, and that like the students in previously described studies, they had little understanding of Earth as a ball in space. Sneider & Pulos (1983) extended the Nussbaum (1979) study to California students in grades three through eight, revamping the notions into two separate categories of shape and gravity. They found a strong age-related trend as before, and through multiple regression analysis, found that differences in verbal ability and spatial reasoning, as well as gender, had the most influence on which notion a student holds.

Jones, Lynch, & Reesink (1987) looked at third- and sixth-grade students' beliefs about Earth's shape, size, and location through a combined use of interviews and model demonstrations. Like those before it, this study found that a larger portion of older students demonstrated a scientifically correct understanding of these topics than younger students did. Baxter (1989) had similar findings in England and used this result to argue that student learning reflects the historical development of astronomy: "The reference to historical ideas possibly makes pupils feel more comfortable when they realize that their notions, although incorrect in the light of scientific advancement, were once the popular view" (1989, p. 512). These results appeared at the same time there was considerable debate among college textbook publishers as to whether astronomy should be presented from an Earth-to-galaxies historical perspective or a Big Bang-to -present-Earth evolutionary perspective (Roettger 1998).

Furthering the work of Nussbaum and colleagues, Stella Vosniadou and her colleagues explored children's understandings by using a cognitive science perspective. Reflective of a changing emphasis in AER, Vosniadou & Brewer (1992) criticized previous researchers for not making sufficiently explicit their notion or category identification criteria, and for providing little or no information on the child's consistency in using that notion in seemingly diverse scenarios. In an earlier article, Vosniadou & Brewer (1987) introduce the concept of knowledge restructuring, whereby changes in knowledge involve the creation of new structures either to reinterpret old information or to account for new information. Knowledge restructuring is further explained in three articles (Samarapungavan, Vosniadou, & Brewer 1996; Vosniadou & Brewer 1992, 1994) that present the details of the researchers' interviewing methods, categorization criteria, and resulting models as summarized below. Results from their research into children's understanding of the shape of Earth were consistent with prior work as described above (Vosniadou & Brewer 1992).

A critical review of all of the research on Earth, its shape, and its place in the universe, including two articles not discussed here, was published in 1997 (Albanese, Danhoni Neves, & Vicentini). These authors divided the previous research into three categories based largely upon an analysis of the types of interview questions used. Research in Group 1, which includes seven studies, focuses on the shape of Earth. Albanese et al. consider that this area of research is complete at the children's level, although note that further research with adults on the topic may be interesting. Three papers are included in Group 2, where the interview questions focus on explicative models without comparing these models to the observations made by the children. This disconnect between observation and model is the key criticism of each paper in this group by Albanese and colleagues. Finally, Group 3 includes two papers that concern a comparison of scientific and traditional culture-based cosmologies. These papers are only briefly described in the review.

At this point, the reader might wonder why this degree of attention has been devoted to these ideas. First, it reflects the community's excitement over unexpected results. Second, the researchers had an intuitive feeling that a student's conception of gravity, another notoriously difficult area of teaching and learning, was dependent upon an accurate conception of a spherical Earth. An example of where this difficulty might make itself known is in the cognitive conflict that a student encounters when trying to understand why penguins in the Antarctic (on the "bottom" of Earth) do not fall off. In the end, this research has not yet dramatically impacted instruction.

2.3 "Here Comes the Sun…" (Studies on Diurnal Motion)

Vosniadou & Brewer's 1994 work focused on children's understanding of the day-night cycle and only indirectly on the shape of Earth. Vosniadou and Brewer analyzed student responses and interpreted the results to suggest that students have three general types of mental models. These are defined as (a) initial models, based on observation and experience and found predominantly in younger children; (b) scientific models, which agree with current scientific theory to a high degree and are held only by a few of the oldest students; and (c) synthetic models, where initial and scientific models are combined in an attempt to reconcile perceived differences between them, which are held by many older children. Vosniadou (as cited in Kikas 1998) claims that students "change their mental models in a way that allows them to retain as many as possible of their experiential beliefs without contradicting adult teachings" (p. 441). This belief is closely aligned with many contemporary developmental and constructivist theories. An example of a synthetic model that demonstrates this theory is the belief that the Sun and Moon, located on opposite sides of Earth, both revolve around Earth every day.

Like Vosniadou and Brewer, V. A. Atwood & R. K. Atwood (1995) investigated the day-night concepts, this time held by undergraduate preservice elementary teachers. They found that the most commonly held alternative conception for the cause of the day-night cycle is that Earth revolves around the Sun. It is worth noting that in both studies, participants often inappropriately used the word "rotate" in their explanations, as in "Earth rotates around the Sun," but that with use of physical models, the same participants often clearly indicated the motion scientifically defined as "revolving" or "orbiting." In fact, Atwood and Atwood improperly used both terms in their explanation of the alternate conceptions held by their participants, although this may have been deliberate in order to illustrate this interchange of terms.

2.4 What Else Can We Ask Them? (Extending Research into Student Understanding)

In 1989, Treagust & Smith investigated students' understanding of planetary motion. They held small group interviews with specific tasks designed to stimulate discussion. The study revealed several unexpected alternative conceptions that were frequently demonstrated by the students, including, for example, that a planet’s rotation depends on the planet’s distance from the Sun and that the rotation rate affects how much gravitational force the planet exerts on an object.

Kikas (1998) conducted a longitudinal study in Estonia regarding students’ ideas about the definitions of the terms equator, axis, and orbit, as well as explanations of the day-night cycle and seasonal change. She first analyzed classroom and textbook coverage of these concepts, then interviewed students in the fifth grade (ages 10 and 11) and four years later. She found that although a large portion of students interviewed could state "correct" (i.e., same as the textbook) definitions within two months of instruction, this number substantially decreased over time. Kikas suggested that the heavy emphasis on short-term memorization from the textbook could account for the large number of students who initially demonstrated accurate understanding that was in fact ephemeral. This is consistent with the idea that if students’ initial understanding is not engaged, they will only learn information for the purposes of a test (National Research Council 1999).

Keith Skamp (Skam 1994; the article was published with a typographical error in the author’s name) uses a technique called a "Card-Sort" to elicit his students’ pre-existing beliefs about astronomy. In this process, students are given cards on which an astronomical idea is written (it may or may not be scientifically accurate) and asked to state whether they agree or disagree (or don’t know) and give their reasoning. By discussing their responses, students’ ideas are brought to the forefront of their minds. The instructor can then analyze and later use written responses to focus instruction on common problem topics. The "Card-Sort" technique has been used in a variety of scenarios throughout education, and although this is not a research-oriented use, it does provide instructors with a simple technique to help them draw out students’ pre-existing ideas about content.

2.5 The Modern Topics (Studies on Cosmology and Astrobiology)

In recent years, a number of outspoken astronomers and astronomy educators have debated the value of teaching and studying traditional topics such as those described above in various venues (e.g., Pasachoff 2001, 2002a, 2002b; Sadler 2001, 2002). For example, Pasachoff (2002b) emphasizes the need to teach those topics that modern astronomers are actively studying, topics that might appear in news reports or magazines. Student understanding of contemporary topics has received little attention in AER until quite recently. In an effort to understand students’ pre-existing mental models about cosmology that might be poised to interfere with instruction, Prather, Slater, & Offerdahl (2002) report preliminary results from a survey of nearly 1,000 middle school, high school, and college students. On a student-supplied written-response survey, students were asked to describe and draw their understanding of the Big Bang. When the responses were inductively analyzed into themes, the authors found that 62% of middle school, 70% of high school, and 80% of college students believed the Big Bang to be an explosion that organized pre-existing matter. In contrast, the more scientifically accepted view of the Big Bang is that of an event that marks the beginning of the expansion of our universe from a single point. In addition to documenting that students have inaccurate conceptual understanding of contemporary topics, the authors also argued for the power of interpreting student responses in terms of phenomenological primitives. P-prims, as these are often called, were first proposed in physics education by Andy diSessa (1993) as a way of interpreting student misconceptions as an internally consistent, fundamental element of knowledge or reasoning. In this case, the authors’ research pointed to a fundamental premise that students bring to the classroom that "you can’t create something from nothing." The authors further propose that such an idea might also account for the common student question of "what is the universe expanding into?"

Another modern topic to find itself under the AER microscope is astrobiology, the interdisciplinary study of life in the universe. Because of the recent popularity of astrobiology as a way to interest students in science, identifying and understanding pre-existing (i.e., preinstructional) beliefs is a key to successful instruction. Offerdahl, Prather, & Slater (2002) undertook this task when they looked at middle school through college students' responses to questions related to the origins, development, and requirements of life. Using student-supplied response surveys, the investigators asked students about the implications for life by sunlight, water, and temperature; limiting environments and their effect on life; and the requirements for the existence of life. Although some 75% of the participating college students were able to cite the general term "microorganisms" as examples of life that might live in conditions considered hostile by humans, many still could not explain, for example, why water is important to the existence of life or what else might be required and why.

2.6 Quantitative Studies in Student Understanding About Multiple Topics

The studies described thus far have used a combination of quantitative data collection techniques, such as surveys, and qualitative ones, like interviews. At the time most of these studies were conducted, no standardized astronomy content test existed, and many researchers simply created their own tests. As noted earlier, Sadler conducted the first large-scale quantitative study as part of his dissertation work in 1992. He later describes the development and analysis of the Project STAR Astronomy Concept Inventory, a revised version of the instrument used in his dissertation (Sadler 1998). One version of the Project STAR instrument was administered to more than 2,500 people (eighth-grade students through professional astronomers). Detailed results are presented for the day-night cycle, seasons, and a model for the Sun and a nearby star. Sadler describes the progress of students' conceptual change with instruction as hopping from one misconception to the next before finding success. He further highlights the contrast between the effective methods demonstrated with Project STAR's hands-on materials and more traditional lecture-based instruction. He says, "The curriculum represented in our nation's textbooks appears to be severely out of line with the results of this study. Concepts are often inappropriate for the grade level at which they are aimed, and mismatched to what students know and can learn" (Sadler 1998, p. 285). This paper received the Outstanding Paper Award from the National Association for Research in Science Teaching (NARST), a distinction that no other work in this review has received.

A cross-age study by Schoon (1992) used an 18-item multiple-choice instrument to investigate the prevalence of alternative conceptions in Earth and space science. Participants included a mix of elementary, secondary, and adult students. Upon looking at the frequency of responses to both the scientifically correct conception and distracters, Schoon classified the alternate conceptions into three categories: (a) primary, where the alternative was chosen more often than the scientifically correct response; (b) secondary, where the alternative conception described was chosen more than twice as often as other distracters but less than the scientifically correct response; and (c) functional, a common alternative conception among younger students that severely interferes with "one's ability to function in today's world" (p. 212). The prevalence of these alternative conceptions was also studied for subgroups of gender, ethnicity, educational level, and school settings (i.e., urban and suburban).

Bisard, Aron, Francek, & Nelson (1994) administered written questionnaires to over 700 students, middle school to college, to investigate Earth science and physical science misconceptions and how they might evolve with educational level. As expected, the mean scores tended to increase with the students' grade levels up to a point; however, the general education majors scored lower than the high school students. The investigators also found that, at the higher education levels, males tended to score higher than females, although no significant differences were observed between genders at the middle school level. They also found a second result particularly worthy of note: preservice teachers who took the test earned approximately the same score as the middle school students involved in the study. These results lend support to an as yet unresearched belief that students' astronomy knowledge does not significantly grow after middle school.

Finegold & Pundak (1990) used a 15-item multiple-choice questionnaire to investigate Australian students' conceptual frameworks in astronomy. Each item's distracters are culled from the literature and can be classified as representative of one of four frameworks: (a) prescientific (characterized by a flat-Earth viewpoint in an unchanging universe); (b) geocentric (changes occur but are Earth-centered); (c) heliocentric (a Sun-centered view in which changes occur in the vicinity of the Solar System); and (d) sidereal (a scientific viewpoint, considering our Solar System's place in the larger universe). With the 330 students in Perth, Australia, who completed the questionnaire, the overall score of correct answers was in the 38%–48% range. Interestingly, the authors suggest that different questions could elicit different mental models within a single student's responses, implying that a specific framework may not be deeply held by a particular student, but rather, that his or her answers might be context-dependent. The researchers did not report conducting extensive statistical analyses to support their inferences; further, the wide range of student responses, coupled with the small number of questions on a number of topics, makes the authors' claims questionable without additional detail. However, their findings contribute to a growing body of indirect evidence that students answer these kinds of astronomy surveys without a deeply embraced conceptual framework.

An open-response "literacy test" was administered to college Earth science students in a study by DeLaughter, S. Stein, C. Stein, & Bain (1998). Several astronomy topics, including orbits, seasons, and gravity, were addressed in the survey. Like previous studies, the investigators found that students hold beliefs that often contradict or incorrectly combine disjointed ideas that scientists consider accurate. Dunlop (2000) administered open-ended surveys to 67 children in Australia to investigate their ideas about the Earth-Moon-Sun system. He found many misconceptions in proportion similar to earlier studies, and includes a table comparing percentages of misconceptions across the studies that he references.

By combining and modifying select questions from earlier multiple-choice tests (viz., Bisard et al. 1994; Lightman & Sadler 1993; Zeilik & Bisard 2000), Trumper (2000) designed his own instrument and used it to report on 76 Israeli university students' prior knowledge in astronomy. He looked at the overall scores on the tests and analyzed individual questions. He reports that most of the questions elicited responses in numbers similar to the original studies from which the questions were taken, and interpreted this result to mean that, like the studies with elementary students 20 years prior, the most common misconceptions span a diversity of cultures. The same survey was used with more than 400 preservice teachers (Trumper 2001c) with similar results. A second version of the survey was given to junior high (Trumper 2001a) and high school (Trumper 2001b) students. Trumper provides question-by-question analyses in each of the four studies.

As a long-duration example of a study on student understanding, Comins (2000a, 2000b, 2001) reports on his requirement that his introductory astronomy (college) students respond to a different question given at the end of each class meeting. This served the dual purpose of taking attendance within a given class and collecting data for the author over nearly a decade of courses. He eventually compiled common misconceptions into a short list (Comins 2000a) and later into a book, *Heavenly Errors* (2001). His complete list is maintained on a Web site (http://www.physics.umaine.edu/ncomins/miscon.htm) and currently includes more than 1,700 ideas. Careful consideration of individual items suggests that some of the ideas are merely factual and might simply be correctable with traditional lecture-based methods, while other ideas might require focused and lengthy instructional interventions, as has been suggested by other studies.

2.7 The Astronomy Diagnostic Test

Building on the work of Michael Zeilik and his colleagues, a multi-institutional team of astronomy educators collaboratively developed a "standardized" test that investigates the most commonly held astronomy misconceptions (Hufnagel 2002; Zeilik 2003). Known as the Astronomy Diagnostic Test (ADT), the instrument uses multiple-choice conceptual questions, revised and validated by extensive student interviews, to probe student understanding in a quantitative way. The most distinctive feature of the instrument is that it uses natural student language rather than scientific vocabulary. Results and demographics of a nationwide administration of the ADT 2.0 (the most current version), which included more than 3,800 students, are kept in a database that allows interested faculty to make comparisons between their own courses and similar ones. National trends and results are described in Deming & Hufnagel (2001). One of the powerful attributes of this instrument is that, although faculty members view the questions as "easy," students routinely do poorly on the survey, implying that the distracters are well selected. The ADT 2.0 is available at http://solar.physics.montana.edu/aae/adt/.

Preliminary work was called the Misconceptions Measure and is described in Zeilik, Schau, & Mattern (1998). Beginning with questions from Project STAR (Sadler 1992), the authors added questions deemed appropriate for the content of the conceptually designed course at the University of New Mexico (UNM). A 15-question subset was administered pre- and postcourse in spring 1995. For the 251 students who took both tests, the mean score increased dramatically from 40% precourse to 69% postcourse (corresponding to an unusually high gain index of $g = 0.48$). Further testing of the Misconceptions Measure is reported in Zeilik & Bisard (2000), where comparable gains were observed for UNM nonmajors ($g = 0.52$) and astronomy majors ($g = 0.49$), and Central Michigan University nonmajors ($g = 0.36$). The authors attribute these gains to a combination of collaborative group learning and cooperative concept maps.

The Misconceptions Measure evolved iteratively into the ADT, as chronicled by Hufnagel and colleagues (Hufnagel 2002; Hufnagel et al. 2000; Zeilik 2003). Because the test covers several topics, it may not reach the depth of understanding of other approaches. Instructors are cautioned by the test authors to not use this as a cumulative test of astronomy knowledge, but rather as a test to compare instructional interventions and to characterize populations.

2.8 What About the Teachers? (Studies on Teacher Understanding)

Teacher beliefs, experiences, and understanding have not yet been studied a great deal in the general educational research literature, so it’s no surprise that these topics are addressed only sporadically within AER. The American Association for the Advancement in Science (AAAS, as cited in Slater, Carpenter, & Safko 1996) suggests that teachers should learn about the excitement and process of inquiry, with adequate content background and an appreciation for the philosophical, historical, and cultural importance of science—just like their students. In a targeted effort to engender this perspective, Slater (1993) used a constructivist approach in the development and evaluation of an in-service course in astronomy for elementary and middle school teachers. Precourse assessments showed that teachers would often avoid astronomy topics because of their lack of confidence and access to high-quality teaching materials consistent with their schools' curricula. After 45 contact hours of constructivist-based instruction, including numerous hands-on activities designed to be implemented in their classrooms, the teachers' self-reported confidence levels, intentions to teach more astronomy, and cognitive test scores improved dramatically. One particularly unique aspect of the instruction was the purposeful inclusion of pedagogy. Teacher-participants were required to submit three-part activity reports each class meeting describing (a) what their students were supposed to learn, (b) what insight they themselves gained by completing the activity in collaborative groups, and (c) what specific changes they needed to make to the activity in order to use it in their individual classrooms. Results and implications are further described in Slater, Carpenter, and Safko. As a follow-up longitudinal study, after four years, teacher-participants from the original study were contacted and asked to complete a self-report questionnaire on knowledge, confidence, and quantity of astronomy instruction (Slater, Safko, & Carpenter 1999). These scores remained consistently high even long after the original course assessments years earlier, lending support to the value of extended professional development programs for teachers (as opposed to brief workshops that serve only to build awareness of content or programs).

Barba & Rubba (1992) investigated the differences in knowledge levels between in-service ("expert") and preservice ("novice") teachers. As might be expected, expert teachers tended to solve problems more accurately and efficiently than novice teachers and appeared to move easily between declarative (or factual) and procedural knowledge. Lightman & Sadler (1988, 1993) investigated whether teachers could accurately predict student performance on a multiple-choice test given both before and after an astronomy course. Although the teachers tended to predict fairly accurately (depending on the topic) their students' responses and performance on the precourse test, they vastly overestimated student scores postinstruction. In fact, the investigators reported that teachers typically predicted a gain (as was defined previously) twice as big as what was observed (Lightman & Sadler 1993).

Atwood & Atwood (1996) studied preservice elementary teachers' understanding of the seasons using both a written instrument and verbal explanations with models. Only 1 of 49 preservice teachers demonstrated a scientific understanding of the concept. Like in *A Private Universe* (Schneps 1989), the most commonly held misconception was that of a varying distance between the Sun and Earth over the course of the year. However, Atwood and Atwood found inconsistencies between the responses elicited by the different methods—no student demonstrated a scientific understanding both on the written instrument and during the interview. This lends further support to the idea that alternative models may not be as deeply rooted as commonly thought.

Trundle, R. K. Atwood, & Christopher (2002) recently investigated the understanding of moon phases held by preservice elementary teachers, and in their report provide a table describing the results of many previous studies on this topic. The researchers collected qualitative data through classroom observations, structured interviews, and document analysis. This triangulation of data through multiple sources is a useful and increasingly common way of checking for valid interpretations. A total of 78 participants were interviewed once or twice to determine their mental models; 63 received inquiry-based instruction on lunar phases during a physics course, while the 15 methods course students received no instruction on the topic. As in most of the earlier studies on this topic, the most common alternative conception about the lunar phases is that they result from eclipses by Earth's shadow. Postinstruction interviews showed that 76% of participants demonstrated scientific understanding after the inquiry unit. A later report (Trundle, Atwood, & Christopher 2003) describes the results of additional postinstruction interviews, 6 and 13 months after the instructional period, with a subset of 12 of the participants receiving instruction in the physics course. None of this subset had scientific understanding before instruction. Three weeks after instruction, eight showed scientific understanding and four demonstrated scientific fragments (in which the participant demonstrated knowledge of some but not all of the four components deemed necessary for complete scientific understanding). Either 6 or 13 months after instruction, seven still held scientific understanding and two demonstrated scientific fragments. The other three reverted to alternative conceptions. The researchers also specified that two common problems seen in the preinstruction interviews were that the participants often did not know that the Moon orbits Earth, or that the Moon is always half illuminated. Without this knowledge, the researchers speculate, students have no reason to question the common shadow eclipse model. The researchers did not use the Lunar Phases Concept Inventory (LPCI) (Lindell 2001) to further investigate their participants' understanding, perhaps because of the LPCI's still-limited dissemination.

It is typical that we most often teach in the way that we were taught. With the emphasis on inquiry in reform documents such as the National Science Education Standards (NSES), many teacher education programs are recognizing the need to model more active learning and teaching strategies. The inclusion of inquiry activities into a science or methods course for preservice teachers is becoming an additional source of research. Ashcraft & Courson (2003) investigated the effectiveness of an inquiry activity with this population. In a pretest-posttest design, they found that the scores of preservice teachers in the course improved significantly on two open-ended questions about seasons after they completed a multisession inquiry laboratory activity. Comparisons with previous nonexperimental offerings of the course showed smaller but still statistically significant improvements after instruction. The authors made no references to the Atwood & Atwood (1996) study described above.

Abell, Martini, & George (2001) used a six-week Moon observation project in their elementary science teaching methods course to emphasize aspects of the nature of science and content. The details of the goals, methods, and assessments used in this process are described in a later report (Abell, George, & Martini 2002). Students recorded daily Moon observations in journals, eventually moving to identifying patterns, making predictions, and offering explanations in the journals as well. Although students were able to recognize the importance of observation in science, they were not often able to articulate the different roles that observation can play. Students were encouraged to develop their own theories to explain their observations, but few students transferred this aspect of "invention" to a scientist's work. Finally, both small- and large-group discussions were used to emphasize the social nature of science. Most of the students recognized the importance of social collaboration in their own learning process, but again failed to make the connection between this aspect and the work of scientists. The authors recognize that much of their instruction about the nature of science was more implicit than perhaps they had hoped, and plan to make these aspects more explicit in future instruction.

Research into teacher education programs is not limited to the United States. Parker & Heywood (1998) describe the effectiveness of a program of study in England about astronomical events. Like previous studies, preservice teacher participants held a number of alternative conceptions at the start of the program, including, for example, the topics of day-night and seasons. Parker and Heywood claim that the most effective way to provide teachers with the skills to teach science is to help them explicitly and deliberately confront their learning processes while investigating the content.

3. RESEARCH ON INSTRUCTIONAL METHODS

3.1 Zeilik's PSI Courses (Studies on Personalized Instruction)

The pioneering work that Zeilik and his colleagues have done on the ADT follows a career of personal research on implementing various instructional methods. In the early 1970s, Zeilik (1974) reported findings from using the Personalized System of Instruction (PSI; also known as the Keller Plan) in an introductory astronomy course at Harvard University. PSI-course students completed lesson units at their own pace without attending a traditional, three-hour-per-week lecture. The class differed slightly from other introductory courses in its emphasis on history and philosophy from an astronomical perspective. Responses on student surveys indicated that the PSI students spent slightly more time on the course (compared with a traditional course), with unit tests and providing immediate feedback as the most important pieces. PSI students also scored, on average, higher on common exams than students in the traditional section did. This is consistent with large-scale implementation studies by Safko (1998). Zeilik reported initial problems with the PSI method, including (a) a lack of student-student interaction, (b) procrastination on the parts of several students in the completion of the units, and (c) increased time demands on the instructor, especially in preparation ("lead time") for the course.

Bieniek & Zeilik (1976) revisited the PSI course with the same survey over seven semesters to investigate whether the personalized instruction remained an effective method, especially given that several novice PSI instructors rotated in and out of the course studied. The immediate and personal feedback provided on the unit tests consistently received high ratings over all semesters. In general, the PSI course continued to receive a positive response even through five different instructors in seven semesters. Zeilik (1981) used the PSI system later with junior-level college courses, which included students with a wide variety of math and physics backgrounds despite the stated prerequisites for the course. This course received high ratings in the areas of (a) learning fundamental principles of astronomy and (b) developing professional skills and viewpoints in the field—two pieces that are often not mastered until graduate work in astronomy is undertaken. Zeilik felt that the system provided much-needed role modeling in science and allowed him to better handle the range of student competencies encountered. In recent years, Slater and colleagues developed a PSI Internet course based on hypermediated interactives (Slater et al. 2003, January). They are finding some success, but not as much as highly interactive engagement courses.

3.2 A Conceptual Course (Studies on Teaching for Conceptual Understanding)

In the 1990s, Zeilik and colleagues created an atypical astronomy course for nonscience majors that was more conceptually based than traditional offerings. Zeilik et al. (1997) describe the details of the design, implementation, and evaluation of this type of course. As part of that work, the investigators deemed four components necessary for the course: (a) the selection of no more than 10 central concepts and their interrelationships in astronomy; (b) the use of these selected concepts throughout the design, implementation, and evaluation of the model course; (c) identification and targeting of students' prior knowledge and misconceptions; and (d) use of a variety of instructional techniques to facilitate increased student learning among all students. To determine the effectiveness of the course, the researchers used four different measures with the 130 students involved in the study. Significant gains were seen on all three conceptual instruments (a multiple-choice misconception measure, g = 0.47; select-and-fill-in concept maps, with a mean score increase near 20%; and a concept-relatedness instrument, g = 0.22). Each of these measures shows an increase greater than one standard deviation from its precourse mean. No significant change was seen in the attitude survey, and both pre- and postcourse administrations reflected slightly positive attitudes as measured on a Likert scale. Reports by Zeilik and colleagues showed similar results for later offerings of the course (Zeilik et al. 1998; Zeilik, Schau, & Mattern 1999). These studies set the stage for the importance of robust study designs with multiple measures used with college students, and are now considered requirements for many rigorous AER papers. Further, Zeilik's multiple measures approaches resonated with traditionally trained astronomers who have been skeptical of AER.

3.3 "So Happy Together" (Studies on Collaborative Learning in Astronomy)

One of the instructional methods that Zeilik has used in his courses is cooperative (or collaborative) learning groups. He collected the lessons he used into an activity book entitled *Interactive Lesson Guide for Astronomy* (Zeilik 1998). The book contains 32 activities that fall into one of four central concept clusters: cosmic distances, heavenly motions, light and spectra, and scientific models.

Another group that has used collaborative groups in the large-lecture course is led by Jeffrey Adams and Timothy Slater. Building upon Zeilik's research-based approaches, their work with this strategy began with an action research study in which the researchers looked for successful and unsuccessful aspects of collaborative group learning (Adams & Slater 1998b). In general, students reported that they enjoyed the in-class activities and felt like they were learning more astronomy from the group activities than from the lecture alone. A total of 16 activities, along with short chapters with supporting background information on related topics, were collected into the *Mysteries of the Sky* textbook (Adams & Slater 1998a). Continuing the original study over several additional semesters, Adams and Slater carefully examined the workings of collaborative groups in this setting. They probed the extent to which these groups help students learn (Skala, Slater, & Adams 2000). An exploration of group dynamics and behaviors showed that female students interact differently in all-female groups as compared to mixed groups (Adams et al. 2002). The researchers designed and used a behavioral protocol to determine the extent to which a subset of 48 groups was actively engaging in the collaborative group activity. They found that females working in all-female groups and equally weighted female and male groups were more engaged in the learning activity than females in unbalanced groups. Despite this result, the authors were not able to provide pragmatic strategies for forcing group composition in very large enrollment courses. Adams & Slater (2002) also have provided a detailed description of successful implementation strategies and "lessons learned" from their classroom experiences. Casey & Slater (2002) describe the use of collaborative groups to complete mid-semester student evaluations of faculty and show that the results are consistently comparable to those from individually completed evaluations.

Expanding the work on collaborative group approaches, the Conceptual Astronomy and Physics Education Research (CAPER) team—including Adams and Slater, among others—have developed a collection of targeted learning activities called "lecture tutorials" (Adams, Prather, & Slater 2002). These tutorials are shorter lessons (on the order of 10 to 20 minutes, as opposed to the 30 to 45 minutes needed for the collaborative group activities described in, for example, Adams & Slater 1998a; Zeilik 1998) designed to be worked on in student pairs and briefly focus on a particular aspect of a larger concept by eliciting and confronting student reasoning difficulties in small cognitive steps. Early results are showing high success rates (Slater et al. 2003, March).

3.4 A "GEM" of a Unit (Studies on Specific Curriculum Interventions)

Sneider & Ohadi (1998) designed a study to judge the effectiveness of an elementary-level instructional unit called Earth, Moon, and Stars (Sneider, as cited in Sneider & Ohadi), developed by the Lawrence Hall of Science as part of the Great Expectations in Math and Science (GEMS) series. The Earth, Moon and Stars GEMS unit of six activities is designed with constructivist and historical approaches in mind and is aimed at grades four through eight. Using the instrument described in Sneider & Pulos (1983), investigators tested the efficacy of the unit through an experimental-control two-group study design. They found that students in the experimental course who used the GEMS unit scored higher on the instrument than those who were exposed to traditional instruction only. Analyses such as Chi-squared tests found that the differences were statistically significant and allowed the researchers to eliminate maturation and pretest learning effects as explanations for the increased scores.

3.5 Let’s Not Forget About the Planetarium (Studies on the Efficacy of Planetarium Instruction)

Over the years, there has been considerable debate about the effectiveness of the planetarium as an instructional tool. Early publications on the matter lacked a substantial research base, according to Reed & Campbell (1972). In one of the earliest AER studies, Reed and Campbell investigated the usefulness of planetarium lessons on diurnal and yearly motions of the stars, planets, and the Sun and on the celestial sphere. The study was based on behavioral objectives and the investigators developed two null hypotheses to be supported or refuted. In this case, college students who were taught to manipulate and rectify (orient) celestial spheres scored higher on cognitive instruments than did students who studied these motions in the planetarium, while no difference was measured in attitudes.

Fletcher (1980) and Mallon & Bruce (1982) both investigated the use of a participatory approach within a planetarium lesson. Fletcher compared this method with the traditional lecture and demonstration approach for teaching the motions of the Sun during the year. He found no significant differences between the two methods in conceptual understanding. Mallon and Bruce evaluated the participatory approach against a more traditional "star show" in the teaching of constellations. In both the cognitive and affective domains, the participatory method showed superiority, while the star show’s instructional effectiveness was not statistically significant. In light of AER results over the last decade, hindsight suggests that these results are more indicative of the degree of students’ intellectual engagement than anything else.

3.6 Additional Thoughts About Instruction

In some instances, an emphasis on students’ understanding of the nature of science infused throughout the course structure seems to have positive effects. Brickhouse et al. (2000, 2002) describe instruction intentionally focused on the nature of evidence and theories in astronomy and the relationship between science and religion. Student interviews, student-generated work, and field notes from class observations were used to demonstrate an increased understanding of the nature of evidence, with slightly lower increases in understanding the nature of theory. Students had some difficulty with the general ideas of theory and evidence, but demonstrated deeper understanding when confronted with specific examples in science. This is consistent with case studies reported by Shawl (2000). Further, the second study by Brickhouse et al. (2002) suggests that student understanding of these issues is science content-dependent.

Throughout the astronomy community, educators and scientists debate the role of mathematics in introductory college courses. Slater & Adams (2002) describe the function of mathematics in their courses. They first differentiate between the use of arithmetic (what is commonly known as "plug-and-chug"), which is kept to a bare minimum, and mathematical reasoning skills, which are instead emphasized. Examples of questions that focus on mathematical reasoning are provided; one is the comparison of two graphs (IQ vs. height and weight vs. height) and the determination of any existing relationships. The choice to use reasoning over formulae, they argue, is more rewarding to students and is more appropriate when modeling real astronomy.

Hemenway et al. (2002) describe their efforts to incorporate nontraditional instructional methods into the introductory astronomy course for nonscience majors. "Hands-on" activities were intermixed with short lecture sessions, while other active learning strategies such as think-pair-share, three-minute papers, and group discussions were incorporated throughout the course. Instruction was modified between two semester offerings to address results from the first semester's action research investigation. Scores on the ADT and the Texas Attitude Survey showed improvement resulting from the instructional changes made in the second semester.

4. ASTRONOMY EDUCATION ARTICLES, WHERE ARE YOU?

Until recently, astronomy education has not had a single "home" in the literature. The purest research might often be found in traditional education journals such as the *Journal of Research in Science Teaching* or *Science Education*. Descriptions of instructional methods, curriculum pieces, and the like are often found in journals such as *The Physics Teacher*, the *American Journal of Physics*, or *The Science Teacher*. Throughout the 1990s, the "AstroNotes" column was a regular appearance in *The Physics Teacher*. This same journal dedicated its December 2000 issue to astronomy in honor of the joint meeting between its parent organization, the American Association of Physics Teachers, and the American Astronomical Society. This issue presented only articles related to astronomy and astronomy education, such as astronomical "hot topics" (Maran 2000), moonquakes (Bailey 2000), interdisciplinary sky gazing (Baker & Heruth 2000), and teaching evolutionary processes (Bobrowsky 2000).

The new online journal, the *Astronomy Education Review (AER)* (http://aer.noao.edu), has already garnered a great deal of support among the community of astronomy educators. Contrary to tradition, the editors at the *AER* are currently posting articles immediately upon completion of the review and editing process, meaning that authors (and readers) don't have to wait to see the results in print (S. Wolff 2002, personal communication).

5. CONCLUSIONS

Taking generous liberty with the idea, it could be said that there are two "founding fathers" in astronomy education research (AER): Philip Sadler and Michael Zeilik. Zeilik works from a university practitioner's viewpoint and focuses on studies that can very directly and pragmatically inform instruction. His early work on personalized instruction and more recently on collaborative group methods is well known throughout the astronomy education community. Sadler's research, on the other hand, stems from an interest in understanding what students know about astronomy and usually focuses on K–12 students. His work on *A Private Universe* (Schneps 1989) in particular dramatically propelled student-understanding research to the attention of professional astronomers and educators alike. Both built upon the work of general education research and incorporated those investigation and analysis methodologies to guide their own investigations in the context of astronomy.

Zeilik and Sadler have both made large impacts on the astronomy education community in recent years. However, they were not officially the earliest contributors to contemporary AER. Some of the first work on student understanding is not widely known outside of the astronomy education community. Joseph Nussbaum and his contemporaries pioneered student-understanding research in astronomy, but this work does not appear to have directly impacted instruction in any obvious way.

Perhaps the largest piece of AER that is still missing today is the practice–theory connection that makes use of the theory-driven research in real classrooms. A second area of research that has yet to be aggressively explored is the underlying cause of student difficulties in astronomy. Three decades ago, Wall (1973) proposed no need for research in student understanding, whereas this is currently seen as the primary area of concern. Part of the reason for this is that the emphases in education, educational psychology, and cognitive science research have changed in recent years. These fields no longer view memorization as sufficient conditions for "knowing" or "understanding," which drives faculty to consider learner-centered approaches to instruction (Slater & Adams 2003). Wall's recommendation for research to develop instructional strategies is still valid, although the thorough evaluation of existing strategies is needed as well. Another area that has some overlap with Wall's recommendations is the need for studies on student variables and their impact on student understanding. For example, there is very little existing work on gender or ethnicity issues in AER. Finally, Wall states, "Research is needed to determine the most effective methods of preparing astronomy teachers at all levels" (p. 665). Very little work has been done in this area, although it is still seen by many as one of the highest and most timely priorities of the field.

The work that will be done in AER in the upcoming years promises to be varied and engaging. As the field continues to grow, new researchers will find their own niches and, it is hoped, fill in some of the gaps that presently exist.

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Astronomy education research (AER) uses the systematic techniques honed in science education and physics education research to understand what and how students learn about astronomy, and determine how instructors can create more productive learning environments for their students. A recent review of the literature in this area revealed a number of articles that could be classified into four major categories: research into student understanding, research on instructional methods, research on teacher understanding, and descriptions of curriculum materials. Type. II. Special Scientific Sessions. Each volume of the Annual Review of Astronomy and Astrophysics acquires a unique flavor, from the initial choices of topics and authors by the Editorial Committee through to the submission of final manuscripts, and we try to capture that flavor in the Introduction. Two themes stand out in this year's volume: the â€œindustrializationâ€ of astronomical data in quantity and the strategy of understanding the average by studying the extremes. Collectively, this volume summarizes a series of remarkable advances on a wide range of astronomy's most fundamental problems. The theme of â€œindustrial dataâ€ is Astronomy education or astronomy education research (AER) refers both to the methods currently used to teach the science of astronomy and to an area of pedagogical research that seeks to improve those methods. Specifically, AER includes systematic techniques honed in science and physics education to understand what and how students learn about astronomy and determine how teachers can create more effective learning environments. PDF | The field of astronomy education is rapidly growing beyond merely sharing effective activities or curriculum ideas. This paper categorizes and | Find, read and cite all the research you need on ResearchGate.Â This paper categorizes and summarizes the literature in astronomy education research and contains more than 100 references to articles, books, and Web-based materials. Research into student understanding on a variety of topics now occupies a large part of the literature. Topics include the shape of Earth and gravity, lunar phases, seasons, astrobiology, and cosmology. The effectiveness of instructional methods is now being tested systematically, taking data beyond the anecdotal with powerful research designs and statistical analyses.

Astronomy Education Review was founded by editors Sidney Wolff and Andrew Fraknoi and published first by the National Optical Astronomy Observatories and, later, by the American Astronomical Society (AAS). Tom Hockey served as editor in the journalâ€™s later years. The journalâ€™s full run of papers is preserved by the AAS at the Portico archive site. Here we present an index to the full contents of the journal, organized by topics that both astronomy education researchers and practitioners would be likely to look under. â€” Andrew Fraknoi (Foothill College). Activities (Classroom, K-12). Reviews the research studies related to astronomy education at the elementary, secondary, and college levels, and makes recommendations for continued research in this area. (JR). Descriptors: Astronomy, College Science, Earth Science, Educational Research, Elementary School Science, Reference Materials, Research, Research Reviews (Publications), Science Education, Secondary School Science. Publication Type: N/A. Education Level: N/A. Audience: N/A. Language: N/A. @article{Bailey2003ARO, title={A Review of Astronomy Education Research}, author={J. M. Bailey and T. Slater}, journal={Astronomy Education Review}, year={2003}, volume={2}, pages={20-45} }. J. M. Bailey, T. Slater. Published 2003. Sociology.Â The field of astronomy education is rapidly growing beyond merely sharing effective activities or curriculum ideas. This paper categorizes and summarizes the literature in astronomy education research and contains more than 100 references to articles, books, and Web-based materials. Research into student understanding on a variety of topics now occupies a large part of the literature. Topics include the shape of Earth and gravity, lunar phases, seasons, astrobiology, and cosmology. Theâ€¦ A Review of Astronomy Education Research. Astronomy Education Review, 2(2), 20â€“45.Google Scholar. Bardar, E.M., Prather, E.E., Brecher, K. & Slater, T.F. (2007). Development and Validation of the Light and Spectroscopy Concept Inventory. Astronomy Education Review, 5(2), 103â€“113.Google Scholar. Baumgardt, C. (1951). Johannes Kepler: Life and Letters.Â Improving Introductory Astronomy Education in American Colleges and Universities: A Review of Recent Progress. Journal of Geoscience Education, 59(4), 176â€“183.Google Scholar. Weintraub, D.A. (2008).