# A Twenty-Year Survey of Science Literacy Among College Undergraduates

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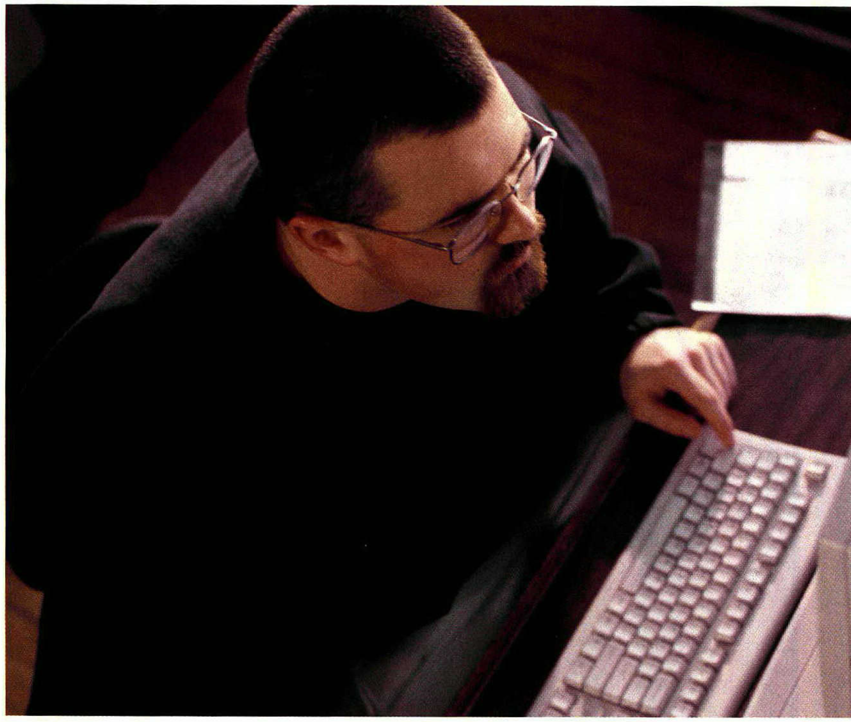
*First results from a 20-year survey of science knowledge and attitudes toward science among undergraduates are presented. Nearly 10,000 students taking astronomy as part of a general education requirement answered a set of questions that overlap a science literacy instrument administered to the general public by the National Science Foundation. The research questions addressed are: What is the level of science literacy among undergraduates, and what variables or attributes predict science literacy? Their attitudes toward science and pseudo-science were probed by a set of 22 statements coded on a Likert scale. On the knowledge items, freshmen perform only marginally higher than the general public, with the exception of large positive differences in their knowledge of evolution and the Big Bang. Gains on any particular item through the time that students graduate are only 10%–15%, despite the fact that they have taken two or three science courses. Belief in pseudoscience runs high, and the fact that the level of pseudoscience belief does not correlate well with the level of science knowledge is particularly noteworthy. In addition, no variable in the analysis is predictive of science literacy. Over the interval 1988–2008, there's no detectable improvement in undergraduate scientific literacy.*



Anyone who teaches undergraduate science plays an important role in our society. If they teach science majors, they fulfill the need for a technically trained workforce by preparing students who are numerate and who have inquiring and analytic habits of mind. If they teach nonscience majors, they often provide the last formal exposure to the evidence-based reasoning and ideas that have transformed our understanding of the natural world.

Advanced math and science are voluntary in most high schools; a majority of students do take biology, but less than a half take chemistry, a quarter take physics, and only 1 in 20 take calculus (Blank, Langesen, and Petersen 2007). At a university, students face a smorgasbord of choices, and despite the popularity of general education science requirements, science is being taken less frequently overall. The National Academy of Scholars surveyed science curricula used in bachelor of arts degrees from the top 50 institutions ranked by the *U.S. News and World Report*; the percentage having science requirements dropped from 90% in 1964 to 34% in 1993, and the percentage with both math and science requirements dropped over the same period from 36% to 12% (Balch and Zurcher 1996). A U.S. Department of Education analysis of the "empirical curriculum" found that science accounted for just 7 of the 100 course categories with the most undergraduates, whereas a third of all future school teachers do not take any college-level math (Adelman 2004). In this paper, we consider the science knowledge and attitudes of a cohort that is typical of the 80% of the students at a major Land Grant public university who graduate with degrees in nontechnical subjects.

## Scientific literacy

Science and technology form an "amniotic fluid" around all who live in the industrialized world and, increasingly, in any part of the world. Americans encounter science in this country in their roles as citizens, workers, and consumers. They vote for political candidates with diverse views on climate change, stem cell research, nuclear power, and the space program. They compete for jobs in technology-driven sectors of the economy that didn't exist a generation ago. They are consumers of ubiquitous high-technology devices and are mostly content to use these tools and other manifestations of scientific ingenuity without any real knowledge of how they work. For good or for ill, science is profoundly shaping human culture, yet any ability to assimilate the insights of scientists into the natural world depends on a foundational understanding of how scientific knowledge is gained, how the scientific

**FIGURE 1**

**The first part of the two-sided questionnaire administered to students in introductory astronomy classes at the University of Arizona in Tucson. The knowledge-based objective response questions include nine that are part of the instrument administered by the National Science Foundation and reported biannually in the *Science and Engineering Indicators* series. The four open-ended questions were transcribed and coded by newly constructed schema.**

- Are you male __ or female __ ?
- Are you a freshman __, sophomore __, junior __, or senior __ ?
- What is your major ________ and estimated GPA ?
- How many science courses have you taken at the U of A __ ?
- What does it mean to study something scientifically? ____________________
- Would you say that astrology is very __, sort of __, or not at all scientific __ ?
- The oxygen that we breathe comes from plants. True or False?
- Lasers work by focusing sound waves. True or False?
- Electrons are smaller than atoms. True or False?
- The universe began with a huge explosion. True or False?
- The continents on which we live have been moving apart for millions of years, and will continue to move in the future. True or False?
- Humans, as we know them today, evolved from earlier species of animals. True or False?
- The earliest humans lived at the same time as the dinosaurs. True or False?
- Which travels faster, light _____, or sound _____ ?
- Does the Earth go around the Sun __, or does the Sun go around the Earth __ ?
- Does the orbit in the previous question take one day __, one month __, or one year __ ?
- What is DNA? ________________________________________________
- What is radiation? ____________________________________________
- If the rate of inflation is falling, are prices decreasing ____, level ____, or increasing ____ ?
- Radioactive milk can be made safe by boiling it. True or False?
- Antibiotics kill viruses as well as bacteria. True or False?
- Is all radioactivity manmade ____, or does some occur naturally ____ ?
- A doctor tells a couple that they have a one in four chance of having a child with an inherited illness. Does this mean that,
  a. If they have only three children, none will have the illness. Yes or No?
  b. If their first child has the illness, the next three will not. Yes or No?
  c. Each of the couple's children will have the same risk of suffering the illness. Yes or No?
  d. If the first three children are healthy, the fourth will have the illness. Yes or No?
- Briefly, define computer software. ____________________________
- Which is the largest contributor to heart disease: smoking ___, eating a lot of animal fat __, stress __, not getting enough exercise __, or lack of vitamins __?

enterprise proceeds, and how to distinguish scientific facts from other kinds of information—a collection of skills and knowledge commonly referred to as *science literacy.*

Scientists in different fields might not agree on a core set of principles and facts that every citizen should know, but they are probably in accord on the fact that science literacy goes beyond their self-interest. To make informed decisions, Americans need to have assimilated enough from their education to use evidence-based reasoning to separate substance from

**FIGURE 2**

**The second part of the questionnaire has 22 statements, with responses on a Likert scale. The items were newly created for this survey.**

| | Strongly agree | Agree | No opinion | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Overall, the progress of science and technology has been beneficial to our civilization. | ☐ | ☐ | ☐ | ☐ | ☐ |
| The Biblical story of creation should be taught alongside evolution theory in our schools. | ☐ | ☐ | ☐ | ☐ | ☐ |
| There are phenomena that physical science and the laws of nature cannot explain. | ☐ | ☐ | ☐ | ☐ | ☐ |
| The positions of the planets have an influence on the events of everyday life. | ☐ | ☐ | ☐ | ☐ | ☐ |
| UFOs are real and should be investigated. | ☐ | ☐ | ☐ | ☐ | ☐ |
| It is almost certain that there are intelligent lifeforms in other parts of the Universe. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Some people possess psychic powers. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Nuclear power is an important energy source and its use should be expanded. | ☐ | ☐ | ☐ | ☐ | ☐ |
| There are some circumstances when medical science should not be used to prolong life. | ☐ | ☐ | ☐ | ☐ | ☐ |
| The Universe was created in an enormous explosion billions of years ago. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Some ancient civilizations were visited by extraterrestrials.. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Computers will eventually be intelligent enough to think like humans. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Technology has too much control over our lives. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Scientists should take responsibility for the bad effects of their theories and inventions. | ☐ | ☐ | ☐ | ☐ | ☐ |
| The government should strongly support the manned space program. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Genetic engineering is a good idea. | ☐ | ☐ | ☐ | ☐ | ☐ |
| We should devote more of our money and scientific resources to repair damage done to the environment. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Pure science should be funded regardless of its lack of immediate benefit to society. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Science will come up with a way to dispose of toxic waste. | ☐ | ☐ | ☐ | ☐ | ☐ |
| We should exert more control over the nuclear weapons developed by scientists. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Faith healing is a valid alternative to conventional medicine. | ☐ | ☐ | ☐ | ☐ | ☐ |
| We should make a concerted effort to search for life on other planets. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Scientists should be allowed to do research that causes pain to animals, if it helps solve human health problems. | ☐ | ☐ | ☐ | ☐ | ☐ |
| Some numbers are especially lucky for some people. | ☐ | ☐ | ☐ | ☐ | ☐ |

spin and cull corroborated fact from unsubstantiated assertion. The health of civic society depends in part on science literacy.

August bodies have weighed in. The Organization for Economic Cooperation (OECD 2002) defines it as understanding key scientific concepts and frameworks, the methods by which science builds explanations based on evidence, and how to critically assess scientific claims and make decisions based on this knowledge. The American Association for the Advancement of Science (AAAS; 1993) states that scientifically literate citizens should be aware that science, mathematics, and technology have strengths and limitations and are interdependent human enterprises; should recognize the unity and diversity of the natural world; and should be able to use scientific ways of thinking and knowledge for individual and social purposes (AAAS 1993). The National Research Council (NRC) has even more lofty goals for the schools: Education should promote science as one of the pinnacles of human thinking capacity; provide a laboratory of common experience for developing language, logic, and problem-solving skills; and prepare students for a democracy, which demands that its citizens make personal and community decisions about scientific issues (NRC 2007).

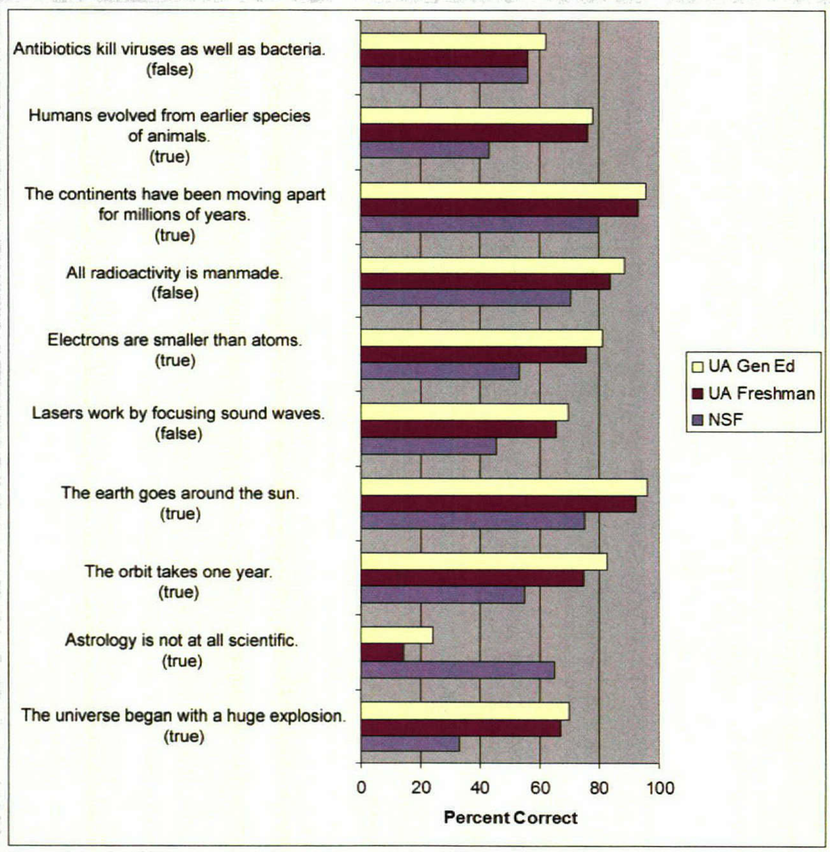
The goal of this paper is to describe a large survey of undergraduate science literacy at one public university, with homogeneous data spanning 20 years. The data is then used to measure the level of science literacy of this population and discover which, if any, variables or attributes are predictive of science literacy.

## Previous measurements

There are many ways to frame the general principles described above into a definition and measurement; therefore, this paper focuses on a survey that tethers to the best longitudinal data available. The National Science Foundation (NSF) has commissioned a survey of science knowledge and attitudes for 20 years as part of the *Science and Engineering Indicators* series, the biannual report to the National Science Board that is used to shape national research and education policy and guide workforce development in technical fields. Jon Miller, who conducted the surveys on behalf of the NSF for many years, set the criteria of literacy to be (1) a vocabulary of basic scientific constructs, (2) an understanding of the process or nature of science inquiry, and (3) a level of understanding the impact of science and technology on individuals and on society. He established a threshold based on (1) coded responses to the question "What does it mean to study something scientifically?" (2) the recognition that astrology is not at all scientific, and (3) correct answers to six or more out of nine knowledge questions (Miller 1987).

**FIGURE 3**

**Responses to subset of items on the science literacy instrument. These items form the basis for NSF knowledge-based metric of public science literacy. UA freshmen have not taken any science classes, whereas UA general education students have taken two to three science classes. Sample sizes are 1,864 for NSF, 1,275 for UA freshmen, and 828 for UA general education; data is from 2006 for NSF and 2004–2008 for UA. The anomalous result on astrology—the very low performance of the college age cohort—seems real, because responses to the separate Likert scale measurement are consistent. UA = University of Arizona; Gen Ed = general education; NSF = National Science Foundation.**



## Methodology

The first author of this paper (CI) has been interested in science literacy for 23 years as an astronomy professor at the University of Arizona (UA) in Tucson. Since 1988, he has administered a survey instrument to the students in general education astronomy lecture classes, taught by himself and his colleagues. The introductory astronomy course counts for a third of the science requirement. About one in five of all undergraduates at the university take the course, which is primarily composed of freshmen and sophomores. Only 5% of the enrollment consists of science majors. The survey is given in the first week of class; it is anonymous and voluntary and doesn't count for any part a student's grade. Typically 10 to 15 minutes are allowed for its completion. Only 3% of the students choose not to complete the survey. Over 20 years, almost 10,000 surveys have been collected and used for analysis in this study.

The rich data set enables us to address a wide range of research questions; this paper summarizes the survey and provides preliminary results to the overarching questions: What is undergraduates' level of science literacy? and What variables are predictive of undergraduates' science literacy? The purpose of this initial look is to establish a baseline of science literacy for this population of undergraduates compared with NSF's national sample and, more specifically, to investigate Miller's (2007) conclusions about the changes in the national sample. This analysis is a precursor to suggestions for the improvement of teaching science to nonscience majors at the college level.

Although the survey is anonymous, the following demographic information is collected: gender, major, self-reported GPA, class standing, and number of science courses taken at the university. The instrument is administered on paper, and subsequent data entry and coding are done by hand. Figure 1 presents the knowledge-based part of the questionnaire. Most of the science content questions are true/false, yes/no, or multiple choice. Four are open response. Nine of the questions overlap with the much more extensive NSF Science Indicators instrument. Figure 2 shows the attitudinal, second half of the questionnaire, comprised of 22 statements about science, technology, and society designed to probe undergraduates' opinions toward science and their belief in pseudoscience. Responses are coded on a 5-point Likert scale, with *no opinion* instead of the more traditional *neither agree nor disagree* as a middle item. This part of the survey was devised by one of the authors (CI) when the survey began in 1988.

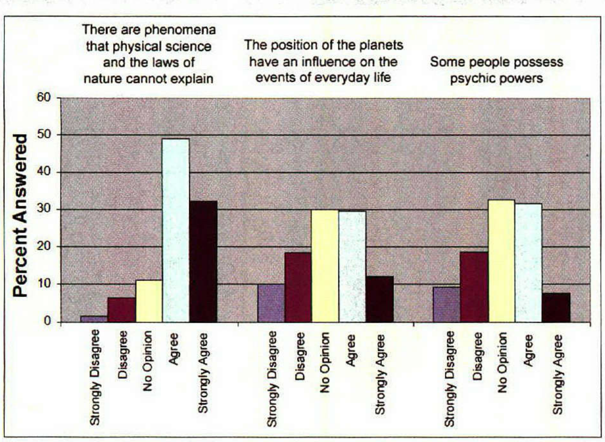
The survey instrument has been stable for over 20 years and has been administered in the same fashion throughout that span. It should be noted that although there is a substantial overlap of knowledge questions with the NSF instrument, NSF calls respondents by telephone at their homes, as opposed to obtaining written responses in a classroom setting. Questionnaires were typically given out with classes of 100 to 150 students, using two to three classes per semester, giving an average of about 500 completed questionnaires per year across the 20 years of the project so far, with fairly uniform time coverage.

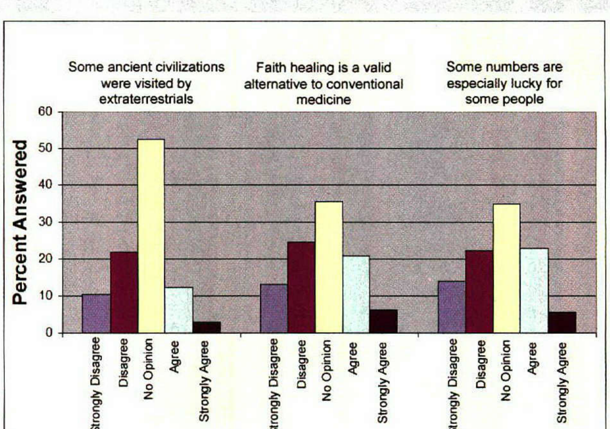
## Data and analysis

The enormous job of data entry was carried out by two of the authors (EJ and CK) over 18 months from 2007 to 2009. The rate of incomplete data, spoiled or bad data, and illegible an-

**FIGURE 4**

**Overall responses, by nearly 10,000 undergraduates over 20 years, to 6 out of 24 statements about science and technology. This is the group of items relating to pseudo-science or nonscientific beliefs. These beliefs coexist with solid performance on science knowledge questions.**



swers or facetious or obviously frivolous responses amounted to around 3% overall. An independent cross-check of a sample of the data showed that error rate for data entry was below 0.1%. Although the survey included both forced-choice and open-response questions, analysis of the forced-choice questions is included here.

Descriptive analysis began by looking at responses to each question, both knowledge as well as belief and attitude questions, by each demographic variable. Next, composite scores were generated on the basis of both overlapping questions with the NSF survey and scores based on all knowledge questions for each individual. Additionally, the belief and attitude questions were grouped into sets using a combination of expert grouping by scientists and science educators, exploratory factor analysis, and cross-validating through confirmatory factor analysis. Both descriptive and regression analysis were used to determine the relationship between the demographic variables and belief and attitude indicators on the one hand, and students' performance on individual (and aggregated) science knowledge questions on the other hand.

## Initial results

UA students got an average of 7.2 (SD = 1.5) items correct out of the 9 items shared on the NSF survey (80%) and an average of 11.2 (SD = 2.3) correct overall out of 15 (75%; the astrology and the inflation questions were left out).

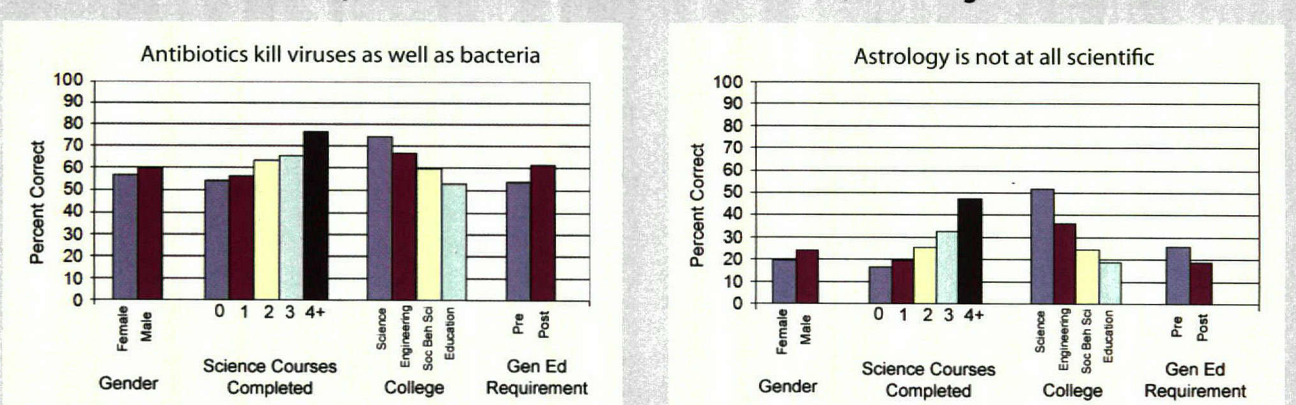
There was an overall stability of questions that were answered correctly over the 20 years. Figure 3 compares the UA sample of both pre-general-education requirement (students equivalent to high school graduates in terms of science courses), post-general-education requirement (students having completed at least two university science courses) to the latest published NSF sample (National Science Board 2008). The UA sample is truncated (2004–2008) to be more comparable to the NSF sample. Figure 3 shows that entering freshmen score marginally higher than the general public, with the exception of large positive differences in their knowledge of evolution and the Big Bang.

The gains in knowledge on any particular item through the time that students graduate are only 10%–15%, despite the fact that they have taken two or three science courses by then. The generally high level of science knowledge is reassuring, but the gain during college amounts to only one additionally correct item among the core set of nine from the NSF instrument, and the gaps that remain are disconcerting. The data show an important gender effect, with slightly better performance by men on the scientific knowledge questions. However, this is the only demographic factor or variable that correlates with performance; it is striking that there seem to be no good predictors of science literacy. Results from this time-limited sample of the UA data are representative of the full data in which UA students perform better than those in the NSF sample but do not show a marked improvement after taking university science courses. Using a full baseline of 1988 to 2008, there's no detectable improvement in undergraduate scientific literacy over 20 years. This contrasts with Miller's (2007) finding for the general public and will be the subject of future analysis.

On the attitudinal part of the survey, students are generally well-disposed toward science and technology and 93% *agree* or *strongly agree* with the statement that "Overall, the progress of science and technology has been

**FIGURE 5**

**The analysis of 9,200 questionnaires for true/false reactions to a statement about antibiotics and 9,300 true/false reactions to a statement about astrology shows a modest but statistically significant gender effect (fewer students answered the question about antibiotics). There's a larger improvement with the number of science courses taken on astrology (from a low base) than on antibiotics. Students who have taken four or more science courses are mostly science majors. Soc Beh Sci = Social Behavioral Science; Gen Ed = general education.**



beneficial to our civilization." Belief in pseudoscience runs high. About 40% believe that the positions of the planets affect everyday life, and the same percentage think some people have psychic powers. About one in six believe that aliens visited ancient civilizations, one in four think that faith healing is a legitimate alternative to conventional medicine, and a quarter think that some numbers are lucky for some people (Figure 4). One striking aspect of the analysis is a null result: None of these beliefs is strongly correlated with level of science literacy.

The results for students who have finished all of their science requirements are disconcerting. One in three think that antibiotics kill viruses as well as bacteria, one in four think that lasers work by focusing sounds waves, one in five think that atoms are smaller than electrons, and one in five either do not believe or are unaware that humans evolved from earlier species of animals and that the Earth goes around the Sun in a year. Only one in five undergraduates say that astrology is "not at all" scientific, although that fraction increases from 17% to 34% as they move through the university. The Likert scale item on the position of the planets is an important cross-check on the astrology question because it does not use the word *astrology* and students might plausibly confuse astrology and astronomy. Equally troubling, half of all science majors say that astrology is either "sort of" or "very" scientific (see Figure 5). In this case, it is possible that they are aware of astrology's roots in observational astronomy, which means the astrology item must be interpreted with caution. Education majors—the cohort of future teachers—perform worse than the average on almost all the individual questions and in terms of overall scientific literacy.

## Summary

Overall, it appears that high school education and students' exposure to media and popular culture convey a basic knowledge of science, although it is piecemeal and barely adequate to make students familiar with the major achievements of science in the past century. After that, college science instruction produces incremental gains, but students still reach the end of their formal education with substantial holes in their knowledge and understanding of science. It is up to science educators and higher education leaders to decide whether it is an acceptable outcome when a significant fraction of college graduates are unaware of major tenets of life and physical science and also hold persistent pseudo-scienctific belief systems.

Future papers will closely examine (1) the relationship between students' beliefs and attitudes and how these attitudes can correlate with science knowledge, (2) the patterns of student belief in pseudoscience in general and belief in astrology in particular, (3) a study of the responses to the open-ended questions and a cross-calibration of undergraduate science literacy with science literacy in the general public, and (4) separate analysis of the differences between the way science is viewed by students and by professional scientists. Another paper will present a new coding scheme for responses to the open-ended question "What does it mean to study something scientifically?" in order to derive a more detailed view of the way students conceive of scientific information and the process of science. ■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