This article describes a study that explored atmospheric science students' ideas about the nature of science (NOS)—what science is and how it works, and its goals, methods, products, and practitioners. Such a study is timely, when atmospheric scientists speak increasingly frequently to the media regarding extreme weather events, climate change trends, and global warming. It is important now more than ever to clearly communicate the NOS to the general public so that they understand how science "works," in order to make informed decisions based on new scientific developments and results. The intent of this article is to highlight some findings from a single case study of atmospheric science students. While broad generalizations based on single case study are not possible, we highlight particular characteristics that may be translatable to other atmospheric science students and the general public. Much like the presentation of a case study of a thunderstorm with unique characteristics that may help one learn something new about thunderstorms in general, the present study is intended to provide some possible insight into the understanding of the NOS of students entering the intensive years of their atmospheric science program, but is not intended to represent all such students. Some practical suggestions for atmospheric scientists interested in reflecting upon their own ideas about the NOS, their communications about science, and developing their own students' ideas about the NOS are also provided.

THE NATURE OF SCIENCE AND SCIENCE EDUCATION. "Science is a study governed by the laws of math and facts. Science is something that is concrete. Scientific laws and theories help
to shape science. Science is different than other disciplines because it is unchangeable. It is not based on thought, feeling or emotions but rather on mathematics. Science usually deals with nature or some form of nature while other disciplines usually do not. Also, most other disciplines lack the ability to prove processes within their discipline most of the time.”

The statement above was written by an incoming junior-level atmospheric science student in response to the question, “What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, atmospheric sciences, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?” A student in the same course at the same university answered these questions as follows: “I believe science is a way to explain processes and use logic to understand the world around us. Science is different from other disciplines because it challenges our belief systems through theory and experimentation. Science is a logical way to problem solve.”

The readers of BAMS, students, the media, and the public may or may not view science in a similar way to one of the above statements. Knowledge about the audience’s understanding of the nature of science can make the communication of science and the education of future scientist more effective.

The NOS is itself a dynamic entity that continues to be studied, evaluated, and debated by educators, philosophers, and sociologists. It involves addressing questions such as the following: What is/are the goal(s) of science and why does it seek this/these goals? What method(s), if any, does it use to reach these goals? What is/are the product(s) of science and what assumptions are inherent to its/their creation? What attributes make a good scientist?

In this study, participants’ ideas about the NOS were interpreted within a framework created primarily by the research instrument, views of nature of science (VNOS). This framework consists of seven general concepts in the NOS that were created by Lederman et al. (2002) to correspond to general areas of agreement among educators, philosophers, and practitioners of science.

These seven general concepts are that scientific knowledge is

- tentative;
- empirically based;
- subjective (only as good as the theory it is derived from);
- the product (at least in part) of human inference, creativity, and imagination;
- embedded in the society and culture in which it operates;
- the product of both observation and inference; and
- composed of knowledge structures, including theories and laws, which occupy unique roles in the creation and representation of scientific knowledge.

The instrument elicited participants’ discussion of these concepts both in the abstract and as they related to specific contexts in science. Our role as researchers was to organize and interpret participants’ responses. Our goal was not to test the participants’ knowledge against a norm, but rather to explore their patterns of thought as they reasoned about the NOS. Burnley et al. (2002) have compared this process of data gathering and interpretation to the use of an oscilloscope. The instrument is not intended to recreate an exact replica of “reality,” rather it creates as signal that can be interpreted to reveal the range and diversity of respondents’ ideas about the nature of science, focusing on the general concepts about the nature of science developed for the instrument.

**PREVIOUS INVESTIGATIONS.** Developing an understanding of the NOS is not a new educational goal. It has been documented as an objective of primary and secondary education as early as the beginning of the last century (Central Association of Science and Mathematics Teachers 1907). Researchers have focused much time and energy examining the NOS ideas of in-service teachers and their students to understand how ideas about science are learned in school (Mackay 1971; Rubba et al. 1981; McComas 1993; Ryan and Aikenhead 1992; Solomon et al. 1996; Songer and Linn 1991; Davis 1997; Lederman et al. 2002; Lederman and O’Malley 1990; Walker et al. 2000; Khishfe and Abd-El-Khalick 2002; Carey et al. 1989; Grosslight et al. 1991). University students’ understanding of the NOS has more recently become an object of interest to researchers. The majority of these efforts have focused on undergraduate students in preservice teaching programs (Bloom 1989; Abd-El-Khalick et al. 1998; Abd-El-Khalick and Lederman 2000), the rationale being that these students will communicate the NOS to the next generation of scientists. However, there has been little research about the NOS ideas that students hold after they have chosen science as their undergraduate major. This is unfortunate because undergraduate science majors will have careers in science and will be communicating with the public about science in both formal and informal settings.
Two studies that have examined the NOS ideas held by undergraduate science majors have found that these students believe that all claims in science can be proved or disproved empirically (Ryder and Leach 1999; Dagher and Boujaoude 1997). A minority of science majors studied by Ryder and Leach (1999) indicated that creativity and imagination are important characteristics for scientists to display. Dagher and Boujaoude (1997) have reported that senior undergraduate biology majors held very narrow definitions of a scientific theory that permitted them to dismiss many of the theories used in field disciplines, such as biology and geology, as “unscientific.” Bezzi (1999) has found that undergraduate geography majors viewed field-based disciplines as less scientific than experimental or laboratory-based disciplines. This small collection of studies show troubling results: many of the ideas about the NOS that undergraduate science students hold are problematic for communicating and promoting science and scientific knowledge to the public and even more problematic for communicating about field-based disciplines of science such as atmospheric science.

This study discussed the NOS ideas held by one class of undergraduate atmospheric science students at a large, research university located in the Midwest. It is our intent that discussing these students’ ideas will provide insight into ways to improve science instruction in all disciplines, so that students leave the university with a deeper understanding of what science is and how it works, and that they can draw on this understanding when communicating about science in all aspects of their lives.

**DESCRIPTION OF THE STUDY.** This study’s goal was to elicit and analyze introductory atmosphericscience students’ ideas about the NOS. Ideas about the NOS are complex and are composed, among other things, of ideas about the nature of reality and how knowledge is created about that reality, ideas about science’s role in society, and ideas about the potential of the individual and the collective group.

To elicit these complex ideas, we employed an open-ended instrument, the Views of Nature of Science–Form C [hereafter VNOS-C (Lederman et al. 2002)], more information can be found in the online supplement (http://dx.doi.org/10.1175/2008BAMS2349.2)]. Items in the VNOS-C include prompts asking the participant to explain the difference between scientific theory and law, and those asking about the effects of social and cultural values on science. The VNOS-C instrument also includes questions that refer to classical problems in chemistry, physics, and biology to provide context for the prompt. To aid in evaluating our interpretations of the participants’ responses, a small fraction of the participants were also interviewed. Questions such as “[W]hat did you mean when you wrote ____” helped to link certain phrases used in the responses with ideas held by the students.

We also collected information about the characteristics and academic background of the participants (gender, major, courses taken, research experience, etc.) with a survey containing closed-response items, so that relationships between the characteristics of the participants and their responses could be explored.

Participants responded to the VNOS-C during the first week of classes at a large midwestern university to undergraduate students enrolled in an atmospheric thermodynamics course offered through the Department of Earth and Atmospheric Sciences in the College of Science and required for all majors in atmospheric science. Typically, 84% of these majors either pursue graduate study in science or are employed as atmospheric scientists after graduation. This course is intended for students beginning their third year of study, typical of atmospheric science programs in the United States, and is the first course where it is assumed they are proficient in multivariate calculus. After taking this course, students in this program diverge into courses specialized for their area of concentration (atmospheric chemistry, atmospheric physics, atmospheric dynamics, or synoptic meteorology); participants were recruited from this course because it is one of the last courses in the sequence that contains students from all concentrations. We chose to recruit participants from this intact atmospheric thermodynamics course to provide a “snapshot” of atmospheric science students’ views at this particular stage in their undergraduate career. At this stage in their programs, the participants would

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1 We use the adjective “introductory” here to emphasize that these are students just entering their junior year of a 4-yr program, and as such, have had a few introductory courses in atmospheric science, but have not yet experienced the intensive courses standard in programs recognized by the American Meteorological Society (AMS).

2 “Open-ended” here refers to the style of response indicated by the instruments prompts, in that participants use their own words, and as many as they want, to explain their answers. “Closed-response” instruments are those that allow the participant to choose one of several preselected responses.
have had a somewhat homogenous math and science background that facilitates examining their ideas as a group. Their prior science and mathematics course work is typical of most large, research-oriented universities: large (300 student) lectures taught by faculty supplemented with smaller (30 student) laboratory and recitation sessions taught by graduate teaching assistants.

A total of 17 students (10 male and 7 female) consented to participate in this study. Two-thirds of the participants were in their third year of undergraduate study and the remaining third were in their fourth year (but had not yet taken the higher-level atmospheric science courses). All participants but two were atmospheric science majors; the two were enrolled in programs in the Colleges of Engineering and Agriculture. One of the atmospheric science majors was also pursuing a second major in geology. All participants in this study described their ethnicity as white, non-Hispanic.

The goal of analysis for this study was to create a snapshot or general description of variety of ideas about the NOS held by these students. Toward that end, we employed a process of categorization and coding or labeling with the participants’ responses, creating frequency tables to display the distribution of ideas about the NOS and provide exemplars. The responses to the VNOS-C and interviews (three subjects consented to be interviewed) were transcribed verbatim, and loaded into a qualitative software program that allowed them to be easily organized and coded for content. These codes were then compared with each other and collapsed to create larger categories that were organized with respect to their relationship to the NOS (Fig. 1). Iterations of this process, as shown in Fig. 1, refined these codes and categories. The VNOS-C and interviews elicited ideas about the definition of science, ideas about scientific knowledge, ideas about the role of evidence in science, and ideas about the scientific enterprise. The responses were organized in these categories because the participants’ ideas transcended the individual questions. For example, the first question asked for a definition of science, but participants also indirectly gave definitions of science in response to the third, fourth, fifth, and sixth questions. Considering only their responses to the first question would have excluded valuable information from the analysis.

The next two sections consist of a discussion of the ideas about the NOS elicited from the participants by the VNOS-C instrument and the follow-up interviews. Common ideas among the participants, and how these ideas may be connected to each other and to the participants’ prior science education experiences, are presented.

**RESULTS AND DISCUSSION.** In this section we discuss participants’ ideas about the NOS. Figure 2 displays the codes that describe the most common of the participants’ ideas about the NOS. The complete set of categories and codes with exemplar quotes for each code can be found in the online supplement to this article.

When examining the major ideas given by participants, a common view of science emerged. They saw the empirical emphasis as allowing science to “prove,” find “facts,” or arrive at “right or wrong answers” about the “world around us” through the accumulation of evidence supporting scientific knowledge, or the endurance of scientific knowledge through a testing process. They believed that scientific knowledge that has survived the testing process, or has accumulated enough evidence, acquires the status of a scientific law and is no longer a scientific theory; in their view, a scientific theory is inferior to a scientific law.

The participants commonly held two related ideas about the role of experiments in science. They felt that experiments tested scientific ideas (nine participants) and that experiments primarily confirmed scientific ideas (15 participants). These two ideas represent the idea that science uses confirming tests to “prove” its assertions; when asked to differentiate

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**Fig. 1.** An overview of the data analysis process.
science from other disciplines, eight participants mentioned that science can "be proven." The students appear to appreciate the importance of data collection in science, but their ideas suggest a "right vs. wrong" ontological position, rather than a position that recognizes the tentative and dynamic aspects of scientific knowledge. This right-versus-wrong view is also common in the public (Rennie and Williams 2006), college students (Abd-El-Khalick et al. 1998; Libarkin 2001; Ryder and Leach 1999), and grade school students (Ryan and Aikenhead 1992).

The participants' belief that science is primarily concerned with "proving" ideas is evident in another commonly held idea about the NOS: "scientific theories mature into scientific laws." When participants were asked about the difference between a scientific theory and a scientific law, 14 of the 17 participants indicated that they viewed the two as being related by a hierarchy of "proof," where a theory is unproven, and once proven, becomes a law. Several responses emphasized the length of time that the knowledge has withstood attempts to disprove it as determining if it was theory or law. Numerous studies have shown that the confusion over the relationship between scientific theories and laws expressed by these atmospheric science students are prevalent among the general public (National Science Board 1996), students (Abd-El-Khalick and Lederman 2000), and university faculty (Wong et al. 2005).

Philosophers, historians, sociologists, and scientists differentiate between laws and theories as kinds of scientific knowledge. Although there are many ways to distinguish between these two types of knowledge, one common example is that a law is an empirically derived relationship expressed verbally or mathematically (Krimsky 1995), and a theory is a well-established, highly substantiated, internally consistent system of explanations often containing assumptions that cannot be tested with observations (e.g., Lederman et al. 2002, and reference therein). Laws describe relationships; theories describe why those relationships exist and can predict where future relationships might be found. Their relationship is not based on a hierarchy of proof. The prevalence of the belief in a hierarchical relationship between scientific theory and law demonstrates the need for increased discussion and reflection about the NOS in all aspects of scientific communication and education. In particular, discussing the diverse use of these terms in science and comparing their scientific meanings with their everyday meanings would be beneficial for students and the public.

The responses to the VNOS-C also allowed an examination of how the students viewed the practitioners of science, with surprising results. A majority (15 participants) saw creativity as an essential attribute for scientists to possess in at least part of their work; most believed that experimental design requires creativity and some also mentioned that the understanding and organizing of scientific data also requires creativity. Only two of this study's participants indicated that creativity was either discouraged or not needed in science. These results are quite opposite from those published previously for undergraduate science majors in other disciplines, which reported that science majors tended to overlook creativity as an essential tool for doing science (Abd-El-Khalick and Lederman 2000).

**POSSIBLE INFLUENCES ON THE PARTICIPANTS' IDEAS ABOUT THE NOS.** One way that participants defined science was by its domain: claiming that science studies the "world around us." In fact, the exact phrase "world around us" was given by six participants, as well as the course instructor. A few participants also emphasized science as the study of "physical objects." It is possible that students have developed this idea about the domain of science in their atmospheric science courses, from their instructors, or have simply self-selected themselves into a discipline that reinforces their ideas about science. Students often relate that their interest in atmospheric science resulted from watching weather phenomena during their childhood, or even witnessing one extreme weather event in their past. This strong interest in atmospheric phenomena may have influenced their beliefs about the domain of science.

![Fig. 2. Ideas about the NOS held by at least 50% of participants.](image-url)
In addition to participants’ personal interests, media coverage and their previous experiences in science courses and discussion may have also influenced their ideas about the NOS. When the participants’ thinking about the processes and products of science were queried, they drew on more recent scientific knowledge or scientific ideas that have been in the news (such as the big bang theory) when referring to ideas that have a lower or “unproven” status. Examples of scientific knowledge that have been “proven” were those that are no longer debated in the media or in the science courses they take at the university (such as Newton’s laws), reinforcing their belief that proven theories become laws.

The influence of their past general science coursework is apparent in their discussions of the roles of evidence in science and their reasons for valuing or not valuing creativity in science. The participants tended to refer to examples resembling the Newtonian mechanics demonstrations used in most introductory physics laboratories: “An experiment is the process of attempting to make science happen with expected results. An example of this is pushing a block across a floor and expecting it to stop at a given point.” This participant’s response indicates that he has learned from his physics labs that science works by confirming “expected results.” Another participant used an example from a chemistry course to argue that creativity is not a part of science: “I do not believe scientists use creativity and imagination . . . Experiments are planned out and executed rigidly without deviation. I remember from past chemistry classes that the labs were rigid.” This student has inferred from her experiences with predesigned laboratory exercises that scientists do not use, and possibly do not need, imagination.

These examples suggest that the students’ perspectives may be strongly influenced about the NOS early in their undergraduate studies by using standardized laboratory exercises that do not reflect the “wonder of discovery” and the creativity required to “investigate the unknown.” Curiously, only one of the participants used an example in atmospheric science when responding to the questionnaire, indicating in a response that scientific knowledge in physics is also used in the Earth and atmospheric sciences, but no participant used examples of activities in atmospheric science to illustrate their ideas about science. This is perhaps a result of the fact that the participants had only had two to three introductory courses in atmospheric science at this point, and their responses might have been different if they had been asked these questions after they experienced the bulk of their atmospheric science courses in the last 2 yr of their program. More likely, however, this is an artifact stemming from the structure of the VNOS-C, because it draws heavily on physics, chemistry, and biology for examples to explain the questions, rather than atmospheric science examples. It was not apparent from the responses that the students saw the field-based methods of atmospheric science as less “scientific,” as found during investigations of other students studied by Dagher and Boulouzade (1997) and Beazzi (1999).

**IMPLICATIONS AND SUGGESTIONS FOR ATMOSPHERIC SCIENTISTS AND EDUCATORS.** What do these results mean for scientists, educators, and employers in atmospheric science? For educators it is important to consider not only the concepts taught, but also the attitudes toward science and about scientists that are cultivated, explicitly or implicitly. Ideas about scientists and their attributes play an important role in encouraging or deterring students from going on to graduate school. Students who do not associate creativity and imagination with science or who view scientists as different from them in some way (race, gender, scholastic background, economic background, etc.) may be very less likely to pursue a career in science. They may leave the major or choose another path after obtaining their degree. This is evidenced by large numbers of women who leave science after finishing their undergraduate education, rather than pursuing careers in industry or pursuing graduate degrees (Blickenstaff 2005).

Discussing personal attributes of scientists, their struggles and conflicts, the obstacles that had to be overcome for new knowledge to be gained, etc., in the classroom is one way in which positive attitudes toward science and scientists might be cultivated. When speaking and writing about science for students and the public, scientists might choose to use an “active voice” that emphasizes that science is a dynamic profession rather than a passive collection of “facts.” Other suggestions for encouraging discussion and reflection on the NOS are included in the sidebar and online supplement to this article.

Some of the results of this study are particularly important for atmospheric science educators to consider when designing their courses. Activities in the laboratory that allow students to confirm scientific laws for themselves (such as Newton’s laws or the ideal gas laws) may mislead students to believe that this is how science is performed. Students are entering their classes having very little experience thinking about how science works, and may benefit from integrated discussion of the NOS into their courses. Introducing
INTEGRATING THE NATURE OF SCIENCE INTO ATMOSPHERIC SCIENCE UNDERGRADUATE COURSES

1) Integrate discussions about the approaches to scientific data collection, analysis and interpretation that are relevant to the topics of the course, such as field studies, laboratory studies, or numerical modeling. In small groups, have students discuss questions such as the following:

- What are the assumptions and limitations inherent in each of these approaches?
- How do you think scientists decide which approach to take?

2) Integrate discussions about the characteristics of scientific knowledge that are relevant to the topics of the course, such as theories and laws. In small groups, have students discuss questions about the role of scientific knowledge in shaping a scientist's understanding of inquiry. Allow the students to analyze the laws, theories, and other scientific knowledge that relate to the topic of the course. Some questions they could consider are as follows:

- Is the scientific knowledge descriptive?
- Is the scientific knowledge explanatory?
- Does the scientific knowledge generate new questions?
- What influence might the scientific knowledge have on a scientist's approach to inquiry?

students to how scientific data collection, analysis, interpretation, and communication take place in their own field develops one's view of the NOS—even at the undergraduate level. These topics can be integrated into existing curricula by initiating discussions or other activities related to the general content of the course. Example discussion topics and questions can be found in the sidebar; resources that address additional ways to integrate the NOS into the classroom are listed in the online supplement to this article. We fully recognize that the nature of science is dynamic and varied, just as the process of science is dynamic and varied through time and across disciplines; we are not advocating indoctrination of students to any single philosophy of science or view of the relationship between science and society. We advocate for the introduction of critical and reflective thinking about the NOS into the curriculum that would encourage students to think critically and creatively about their field and produce more innovative and thoughtful scientists.

Communication problems between scientists and the media, the oversimplification of scientific knowledge in the media, and the reinforcement of poor representations of science within the science curriculum from grade school through college all serve to confuse the general public's understanding of the NOS. The active debate currently begin played out in the media about the existence and causes of climate change could be leading students and the public to infer that this scientific knowledge is in some way inferior to the knowledge that is taken for granted (such as Newton's laws) in their other science courses. It may be beneficial for scientists to reflect upon their own ideas about the NOS, and examine if their word choices truly represent what they want to communicate about the NOS. Knowing that the public will possess different definitions of scientific terms like theory and law, scientists might be more explicit about the definitions employed and connect these definitions to ongoing work in science. Connecting dialogues with students, the public, and the media to concrete examples of how science is performed in our field may help them recognize atmospheric science as a dynamic, exciting field in which they can use their creativity, imagination, and ingenuity to make meaningful contributions to knowledge, technology, and society.

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3 References for some written works about the NOS that can assist in this reflection are supplied in the online supplement.


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