Understanding Science
how science *really* works

Educational research on teaching the nature and process of science

The teaching resources recommended on our site are consistent with what is known about how students learn the nature and process of science. Educational research suggests that the most effective instruction in this area is explicit and reflective, and provides multiple opportunities for students to work with key concepts in different contexts. But just how do we know that this sort of instruction works? And how do we know which concepts are hardest for students to learn and which are the most difficult misconceptions to address? To find out, read the following journal articles from the education research literature summarized below. These help reveal how we know what we know about how students learn.

Abell, S., M. Martini, and M. George, M. 2001. "That's what scientists have to do": Preservice elementary teachers' conceptions of the nature of science during a moon investigation. ***International Journal of Science Education*** **23(11):1095-1109.**

Two sections of an undergraduate course in elementary science education were observed during an extended investigation, in which students made observations of the moon and tried to develop explanations for what they saw. Students worked in groups, were engaged in many aspects of the process of science, and were asked to reflect on their own learning regarding the moon. Eleven student journals of the experience, along with interview transcripts from these students, were analyzed for student learning regarding observation in science, the role of creativity and inference in science, and social aspects of science. Major findings include:

- Students recognized that observations are key in science but didn't recognize the role that observation plays in science.
- Students recognized that their own work involved observing, predicting, and coming up with explanations, but they did not generally connect this to the process of science.
- Students recognized that collaboration facilitated their own learning but did not generally connect this to the process of science.

This research highlights the pedagogical importance of making the nature and process of science explicit: even though students were actively engaged in scientific processes, they did not get many of the key messages that the instructors implicitly conveyed. The researchers also recommend asking students to reflect on how their own understandings of the nature and process of science are changing over time.

Akerson, V.L., F. Abd-El-Khalick, and N.G. Lederman. 2000. Influence of a reflective activity-based approach on elementary teachers' conceptions of nature of science. ***Journal of Research in Science Teaching*** **37(4):295-317.**

Fifty undergraduate and graduate students enrolled in a science teaching methods course engaged in six hours of activities designed to target key nature-of-science concepts, consistent with those outlined in Lederman and Lederman (2004). After the initial set of activities and throughout the course, students were encouraged to reflect on those concepts as opportunities arose within the designated pedagogical content, and were assigned two writing tasks focusing on the nature of science. By the end of the course, students were so accustomed to these reflections that they frequently identified such opportunities for themselves. Students were pre- and post-tested with an open-ended questionnaire targeting the key concepts, and a subset of students was interviewed on these topics. Responses were analyzed for key concepts to determine whether students held adequate conceptions in these areas. Major findings include:

- There were few differences between graduates and undergraduates: most students began the course with largely inadequate conceptions.
- Students began the course understanding least about the empirical nature of science, the tentative nature of scientific knowledge, the difference between theories and laws, and the role of creativity in science.

- Significant gains were achieved as a result of instruction. Student conceptions improved most in the areas of the tentative nature of scientific knowledge, the difference between theories and laws, and the difference between observation and inference.

The explicit, reflective instruction was effective, but despite the gains achieved, many students still held inadequate conceptions at the end of the course. This supports the idea that students hold tenacious misconceptions about the nature and process of science, and, the authors argue, suggests that instructors should additionally focus on helping students see the inadequacy of their current conceptions. The authors suggest that the role of subjectivity, as well as of social and cultural factors, in science are best learned through rich historical case studies, which are hard to fit into a methods course. Finally, the authors conclude that nature-of-science instruction is effective in a methods course, but would likely be more effective in a science content course.

Kang, S., L. Scharmann, and T. Noh. 2004. Examining students' views on the nature of science: Results from Korean 6th, 8th, and 10th graders. *Science Education* 89(2):314-334.

A multiple-choice survey (supplemented by open-ended questions) on the nature and process of science was given to a large group of 6th, 8th, and 10th grade students in Korea. Most students thought that:

- Science is mainly concerned with technological advancement
- Theories are proven facts
- Theories can change over time
- Scientific knowledge is not constructed, but discovered (i.e., can be read off of nature)

Interestingly, Korean students don't tend to hold the common Western misperception of theories as "just hunches." The researchers found little improvement in understanding in older students. This suggests that special attention is needed to help students learn about the nature of science. The researchers argue that we should begin instruction in this area early in elementary school.

Khishfe, R., and F. Abd-El-Khalick. 2002. Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching* 39(7):551-578.

Two sixth grade classes (62 students total) in Lebanon experienced two different versions of a curriculum spanning ten 50 minute segments. One class participated in an inquiry-oriented science curriculum, which included a discussion component that explicitly emphasized how the nature of science was demonstrated through student activities. The other participated in the same inquiry curriculum, but their discussion focused exclusively on science content or the skills students had used in the activity. Both groups completed open-ended questionnaires and participated in interviews regarding their views of the nature of science before and after the intervention. The two groups started off with similar, low levels of understanding, but the students in the class with explicit discussion of the nature of science substantially improved their understanding of key elements of the nature of science (the tentative, empirical, and creative nature of scientific knowledge, as well as the difference between observation and inference) over the course of the intervention. The other group did not. However, even with the enhanced, explicit curriculum, only 24% of the students achieved a consistently accurate understanding of the nature of science. These findings support the idea that inquiry alone is insufficient to improve student understanding of the nature of science; explicit, reflective instruction is necessary as well. The researchers further conclude that this instruction should be incorporated throughout teaching over an extended period of time in order to see gains among a larger fraction of students. The researchers emphasize that explicit, reflective teaching does not mean didactic teaching, but rather instruction that specifically targets nature of science concepts and that provides students with opportunities to relate their own activities to the activities of scientists and the scientific community more broadly.

Lederman, N.G. 1999. Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching* 36(8):916-929.

Five high school biology teachers were observed weekly for one year to examine whether their conceptions of the nature of science were reflected in their teaching. The researcher also collected data from questionnaires, student and teacher interviews, and classroom materials. All five teachers had accurate understandings of the nature of science.

The most experienced teachers used pedagogical techniques consistent with the nature of science, though they weren't explicitly trying to do so and did not claim to be trying to improve students' understanding of the nature of science. Less experienced teachers did not teach in a manner consistent with their views of the nature of science. This suggests that an adequate understanding of the nature and process of science and curricular flexibility alone are not sufficient to ensure that teachers will use pedagogical techniques that reflect that understanding. In addition, the researchers found that students in these classrooms gained little understanding of the nature of science, regardless of whether they were taught by a more or less experienced teacher. This lends further support to the idea that teachers need to be explicit about how lessons and activities relate to the nature and process of science in order for students to improve their understandings in this area. The researcher concludes that teacher education programs need to make a concerted effort to help teachers improve their ability to explicitly translate their understanding of the nature of science into their teaching practices. Furthermore, teachers should be encouraged to view an understanding of the nature of science as an important pedagogical objective in its own right.

Lederman, N.G., and J.S. Lederman. 2004. Revising instruction to teach nature of science. *The Science Teacher* 71(9):36-39.

The authors describe seven aspects of the nature of science that are important for K-12 students to understand:

- the difference between observation and inference
- the difference between laws and theories
- that science is based on observations of the natural world
- that science involves creativity, that scientific knowledge is partially subjective
- that science is socially and culturally embedded
- that scientific knowledge is subject to change.

They argue that most lessons can be modified to emphasize one or more of these ideas and provide an example from biology instruction. Many teachers use an activity in which students study a slide of growing tissue and count cells at different stages of mitosis in order to estimate the lengths of these stages. The authors recommend modifying this activity in several ways:

- asking students to reason about how they know when one stage ends to emphasize the sort of subjectivity with which scientists must deal
- asking students to grapple with ambiguity in their data
- asking students to reason about why different groups came up with different estimates and how confident they are in their estimates in order to emphasize the tentativity of scientific knowledge
- asking students to distinguish between what they directly observed on the slide and what they inferred from those observations.

The authors emphasize that incorporating the nature and process of science into this activity involves, not changing the activity itself, but carefully crafting reflective questions that make explicit relevant aspects of the nature and process of science.

Lederman, N.G., and D.L. Zeidler. 1987. Science teachers' conceptions of the nature of science: Do they really influence teacher behavior? *Science Education* 71(5):721-734.

Eighteen high school biology classrooms led by experienced teachers were studied over the course of one semester. Teachers' understandings of the nature and process of science were assessed at the beginning and end of the semester. In addition, the researchers made extensive observations of each classroom at three different points in the semester and categorized the teachers' and students' behaviors along many variables relating to teaching the nature and process of science. The researchers found *no* relationship between a teacher's knowledge of the nature and process of science and the teacher's general instructional approach, the nature-of-science content addressed in the classroom, the teacher's attitude, the classroom atmosphere, or the students' interactions with the teacher. This finding challenges the widely held assumption that student understanding of the nature and process of science can be improved simply by improving teacher understanding. Instead, the teachers' level of understanding of this topic was unrelated to classroom performance. The authors emphasize that this doesn't indicate that a teacher's ideas don't matter at all; teachers need at least a basic understanding of the topics they will teach, but this alone isn't enough. The authors suggest that to improve their teaching in this area, instructors also need to be prepared with strategies designed specifically for teaching the nature and process of science.

Moss, D.M. 2001. Examining student conceptions of the nature of science. *International Journal of Science Education* 23(8):771-790.

Five 11th and 12th grade students, with a range of academic achievement, taking an environmental science class, were interviewed six times over the course of a year. The class was project-based and engaged students in data collection for real scientific research. Interviews focused on students' views of selected aspects of the nature and process of science. The researcher coded and interpreted transcripts of the interviews. Major findings include:

- In contrast to previous studies, most students understood that scientific knowledge builds on itself and is tentative. Students also seemed to understand science as a social activity.
- Many students didn't know what makes science science and had trouble distinguishing science from other ways of knowing.
- Many students viewed science as merely procedural.
- Most students didn't understand that scientists regularly generate new research questions as they work.
- Despite the authentic, project-based nature of the course, there were few shifts in student views of the nature and process of science.

This research supports the view that explicit instruction is necessary to improve student understanding of the nature/process of science. The researcher suggests that this can be done by having students develop their own descriptions of the fundamentals of the nature and process of science. The researcher also suggests that teachers need to focus on helping students understand the boundaries of science, perhaps by explicitly discussing how science compares to other human endeavors.

Sadler, T.D., F.W. Chambers, and D. Zeidler. 2004. Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education* 26(4):387-409.

A group of average- to below average-achieving high school students was asked to read contradictory reports about the status of the global warming debate and answer a series of open-ended questions that related to the nature and process of science. Each report included data to support its conclusions. The researchers examined and coded students' oral and written responses. On the positive side, the researchers found that:

- Most students understood that science and social issues are intertwined.
- Most students were comfortable with the idea that scientific data can be used to support different conclusions and that ideological positions may influence data interpretation.

However:

- Almost half of the students were unable to accurately identify and describe data, and some conflated expectations and opinions with data.
- There was a tendency for students to view the interpretation consistent with their prior opinion as the most persuasive argument—even in cases where they judged the opposite interpretation to have the most scientific merit. This suggests that students may not incorporate scientific information into their decision-making process, dichotomizing their personal beliefs and scientific evidence.

The researchers suggest that instruction should focus on the above two issues and that teachers should encourage students to consider scientific findings when making decisions. In addition, students should be encouraged to deeply reflect on socioscientific issues and consider them from multiple perspectives.

Scharmann, L.C., M.U. Smith, M.C. James, and M. Jensen. 2005. Explicit reflective nature of science instruction: Evolution, intelligent design, and umbrellaology. *Journal of Science Teacher Education* 16(1):27-41.

Through multiple iterations of a preservice science teacher education course, the researchers designed a 10 hour instructional unit. In the unit, students:

- attempt to arrange a set of statements along a continuum from more to less scientific
- develop a set of criteria for making such judgments
- participate in a set of inquiry activities designed to teach the nature of science (e.g., the black box activity)
- read and reflect on articles about the nature of science
- analyze intelligent design, evolutionary biology, and umbrellaology (a satirical description of the field of umbrella studies) in terms of the criteria they developed.

The final iteration of this set of activities was judged by the authors to be highly effective at changing students' views of the nature of science and perhaps even helping them recognize that intelligent design is less scientific than evolutionary biology. Furthermore, the researchers suggest that using a continuum approach regarding the classification of endeavors as more or less scientific may be helpful for students who have strong religious commitments and that explicit, respectful discussion of religion in relation to science early in instruction is likewise important for these students.

Schwartz, R.S., N.G. Lederman, and B. Crawford. 2004. Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education* 88(4):610-645.

A group of preservice science teachers participated in a program that included 10 weeks of work with a scientific research group, discussions of research and the nature of science, and writing prompts which asked the preservice teachers to make connections between their research and the process of science. Participants were interviewed and observed, and responded to a questionnaire about the nature of science. Eighty-five percent of the participants improved their understanding of the nature of science over the course of the program. The two participants who did not improve their understanding were the two that focused on the content of their research and did not reflect on how this related to the nature of science. Participants also seemed to gain a better understanding of how to teach the nature and process of science explicitly. The researchers conclude that the research experience alone did little to improve students understanding, but that this experience was important for providing the context in which active reflection about the nature and process of science could occur. They recommend that scientific inquiry in the K-12 classroom incorporate reflective activities and explicit discussions relating the inquiry activity to the nature and process of science.

Zeidler, D.L., K.A. Walker, W.A. Ackett, and M.L. Simmons. 2002. Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education* 86(3):343-367.

A sample of 248 high school and college students were given open-ended questions eliciting their views of the nature of science. In addition, researchers elicited students' views on a socioscientific issue (the appropriateness of animal research) using both a Likert scale item and open-ended questions. From this large sample, 42 pairs of students with differing views of the appropriateness of animal research were selected. These pairs of students were allowed to discuss the issue with each other and were probed by an interviewer. Finally, they were presented with data anomalous to their own view and were probed again on their confidence in the data and their willingness to change their view. Researchers analyzed these 82 students' responses to the open-ended questions using concept mapping and compared their responses to Likert items. They found that students *did* change their views on the issue as a result of discussion and exposure to anomalous data. They also found that younger students tended to be less skeptical of anomalous data presented to them from an official-sounding report. In only a few cases were students' views of the nature of science obviously related to their analysis of the socioscientific issue. These were mainly situations in which a student expressed a belief that scientists interpret data to suit their personal opinion, and then, correspondingly, the student selectively accepted or rejected evidence according to whether it supported his or her opinion. In addition, many students seemed to believe that all opinions are equally valid and immune to change regardless of the scientific evidence. The authors conclude that instruction on the nature of science should be incorporated throughout science courses and should include discussion in which students are asked to contrast different viewpoints on socioscientific issues and evaluate how different types of data might support or refute those positions.