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"A Scientist Has Many Things to Do:" EPO Strategies that Focus on the Processes of Science

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Abstract. Scientists' effort in education and public outreach (EPO) is best invested in sharing their expertise on the nature and processes of science—the "understandings of science" that are emphasized in the National Science Education Standards, but that are difficult to teach and poorly supported by existing curricular materials. These understandings address the intellectual process of science—posing questions, gathering and interpreting evidence—and the social process of science as a human endeavor for building knowledge. We share several ways of incorporating concepts about the nature and processes of science into EP/O activities and making them focal points in their own right. Hands-on activities used at science festivals and in classrooms and professional development workshops illustrate key scientific thinking skills such as observing, classifying, making predictions, and drawing inferences. A more comprehensive approach is exemplified by *Upward and Outward: Scientific Inquiry on the Tibetan Plateau*, a 20-minute educational documentary film for school science classrooms and teacher professional development. The film portrays the intellectual and human processes of science through an inside view of a research project; classroom assessments offer evidence of its impact on students' ideas about these processes.

1. Understanding the Processes of Science: Opportunities and Needs

As a profession, education and public outreach (EPO) work is founded on the premise that scientists and scientific organizations have a duty to communicate with the general public as well as with their disciplinary and technical colleagues (Fraknoi 2005). Research funding agencies, including NASA and the National Science Foundation, have institutionalized this premise through expectations of their grantees, for example to make a "robust and substantial" commitment to EPO activities (NASA 2008) or to communicate the "broader impact" of research (e.g., NSF 2003). In response, universities, laboratories and research institutes have developed outreach offices; scientists and educators have developed programs and partnerships to reach children, youth and adults in school, out-of-school, and public settings; and universities are beginning to incorporate these activities into their evaluation and rewards structures (Dolan 2008).

The need for such effort by scientists can be seen in many facets of society. Many adults cannot correctly answer simple factual questions about scientific concepts and processes of investigation (National Science Board 2010). Misconceptions about how science works allow pseudoscience to thrive and fuel controversy about climate change and the teaching of evolution in schools. Stereotypes of scientists as brainy but socially awkward loners who craft explosives and poisons and who communicate in formulas are widespread and surprisingly robust over time and across cultures (Chambers 1983; Finson, Beaver, & Cramond 2002; Sjøberg 2000).

National documents such as the National Science Education Standards (NSES) (1995; see also American Association for the Advancement of Science (AAAS) 1990) articulate goals for science learning that address these understandings of the nature and processes of science. The goals for all students are:

- to learn science—the central concepts and key supporting facts of science;
- to learn to do science—the procedural skills and habits of mind that are needed to conduct an investigation; and
- to learn about science—the understanding that science is a human activity and a means of constructing knowledge.

The latter two goals emphasize the practice of science rather than the body of knowledge already developed through those practices. While the NSES and AAAS documents frame these goals for school children, we argue that these are equally critical understandings for adults—in an information-rich age, even more important than knowing particular facts and ideas. With their deep experience of doing science, scientists are uniquely placed to illuminate these understandings, which cut across disciplines yet are enriched by discipline- and project-specific examples.

Here and elsewhere (Laursen 2006; Laursen & Smith 2009) we describe several approaches that scientists can use to share these understandings with varied audiences in their EPO work. First, we describe several hands-on activities that can be used in varied contexts to emphasize particular intellectual processes or skills of investigation. Then we describe an integrated approach to communicating both the intellectual and social processes of science, through a short educational documentary that shows students how real scientists work.

2. Hands-On Activities Emphasizing the Intellectual Processes of Science

The process of scientific inquiry involves posing questions, gathering evidence, developing and testing explanations, and communicating findings. The activities described here emphasize one or more elements of inquiry and help participants develop the logical and reasoning skills of investigation. A key feature of all the activities is that they place skills or processes at the center and do not simultaneously introduce new scientific content. Using everyday or invented objects and familiar contexts, participants can better practice and reflect on the scientific skill or process as a central learning objective, without being distracted by new facts and concepts and without privileging learners who may already know some of these facts.

2.1. Sorting and Classifying: At Home or At Large in the Solar System

Classification is a fundamental scientific activity in which even very young children can participate. As scientists observe and describe objects and phenomena, they notice patterns that may or may not be meaningful and organize their observations accordingly. As new observations or measurements are made, classification systems must evolve to reflect additional details, reorganize objects or phenomena, and prioritize certain properties in ways that add meaning and help to build explanations. At heart, classification systems help scientists communicate with each other.

Because classification is such a basic scientific activity, we often preface EPO activities with a simple sorting activity to highlight classification and give participants practice with classification before diving into new scientific information. Small plastic bags containing a dozen household objects—paper clips, bottle caps, small toys, gum wrappers, and so on—are distributed to each group. The group must propose and share a classification scheme for their objects. As quickly becomes apparent, many right answers are possible; different schemes will be useful for different purposes; and sometimes a category of "not like the others" is an intellectually defensible and useful choice until more information comes along.

We have used the baggies with a wide range of audiences—as a stand-alone sorting activity for first graders, as a lead-in to a mini-lecture on the reclassification of Pluto for a general adult audience, and as a precursor to a solar system card sort (Hurst 2007) with teachers at a professional development institute. In the latter example, as participants sort cards with pictures and facts about individual solar system objects, they must grapple with the fact that Pluto's properties are not very similar to those of the other planets, but more like those of other recently discovered objects. As improved observational technology has revealed hundreds of previously unknown objects, Pluto and Ceres are seen to join a much larger class of dwarf planets. Such reclassification is not only valid, but a very appropriate adjustment to the "facts" of science when new facts become known. Frequently the discussion provides an opportunity to point out that objects in the universe do not come with labels: naming and classifying are human ways of organizing our observations and ideas.

2.2. Mystery of the Iceman

In the Mystery of the Iceman (BSCS 2006), participants imagine they are archeologists who must interpret the artifacts preserved with a Bronze Age man found frozen in the Swiss Alps. They read an engaging true story and work with a table listing the artifacts and their properties—weapons, clothing, food, sewing tools, and other personal items. Clothing and shoes are easily interpreted, but other items are more puzzling: how did the Iceman use mushrooms threaded on a leather strip? Follow-up questions ask participants to carefully distinguish evidence from inference and invariably prompt lively discussion of how these may be defined.

We have used the Iceman activity with middle and high school students, with teachers in short and long workshops, and with scientists in EPO workshops intended to help them use and teach inquiry skills (Laursen & Smith 2009). For example, in a geology workshop for teachers, it functioned as an effective lead-in to activities on inferring past environments from the properties of sedimentary rocks. By practicing the skill of making inferences and more sharply considering the meaning of these terms, teachers were better able to separate their field observations from their inferences and to communicate accurately about the evidence they gathered and their interpretation of it. In turn, many of these teachers used the activity with their own students for a similar purpose. We have also found this activity helpful in climate change education, helping teachers to more clearly identify the evidence and the varied inferences that may follow.

2.3. Mystery of the Black Box

The Mystery of the Black Box is a versatile activity that engages participants in many aspects of scientific inquiry: making observations, developing and testing hypotheses, combining results into a model, making arguments and persuading others. Without opening it, participants must investigate a sealed black box that contains internal barriers and a small ball whose hidden but audible movement is used to identify the location and shape of the barriers. As they probe the workings of their box in small groups, participants develop and sketch a model of the box interior, then present it to the rest of the class.

Based on an activity from a Full Option Science System (FOSS) science kit for grades 5–6, *Models and Designs*, the activity can be brief or quite extended. For younger students, it can be used to develop skills of investigation and model-building; with older students and teachers, it can set up a discussion of a particular disciplinary model such as the atom, the interior of the Earth, or motions within the solar system. Black boxes can be constructed using materials available from FOSS or purchased from scientific supply houses under the name "Obscertainer." A lesson plan from the University of California-San Francisco's Science and Health Education Partnership (SEP) is a useful overview.

We have used guided-inquiry variations of the Black Box activity in elementary and secondary classrooms and in workshops for science teachers and EPO educators. At science festivals and fairs, a simpler version of the activity invites participants to "think like a scientist" and "use your senses" to explore the box. They can draw their model on a pre-printed form and compare it with posters showing "models proposed by other scientists" that include both accurate models of the box interior and plausible alternatives. This is a popular activity for all ages: young children enjoy simply shaking the box and listening to the rolling ball inside, while older children may stay engaged long enough to test several different boxes. Adults are often more reluctant to dive in (and more concerned about being "right"), but can be encouraged to interact with their children and experiment with boxes for themselves. Thus this activity can be enjoyed as a stand-alone scientific experience or used in formal education to teach about model-building.

3. An Inside View of the Social and Professional Processes of Science

Based on successful experimentation with methods for "learning to do science," we tackled the even more difficult goal of "learning about science." We sought to replace the standard presentation of *the* scientific method so typical in the opening chapter of secondary school textbooks with a more engaging, accurate, and complex portrayal of how science works. By using the actual workings of a particular scientific research project, we wished to show, rather than tell, how scientists work—to depict both the intellectual processes of investigation and the social and professional activities of people doing science as a job. As a medium, we chose documentary film to create a robust product that would fill a gap in available curriculum, support flexible use in a variety of ways and in a variety of classrooms, and leverage the researchers' time to yield an EPO product that could be widely distributed. In this section, we describe the film and the evidence we gathered about its impact on viewers.

3.1. Making the Documentary

Upward and Outward: Scientific Inquiry on the Tibetan Plateau is a 20-minute educational documentary film for school science classrooms and teacher professional development. The film portrays the intellectual and human processes of science as seen through the work of an international team of scientists on an interdisciplinary geoscience research project. Funded as a "broader impact" component for a large, collaborative and international research study in geoscience, the film set out to:

- portray both the intellectual process of scientific inquiry—posing and investigating questions—and the social process of science as a human endeavor;
- show science as a profession with places for people of varied backgrounds, skills and interests, doing a variety of jobs;
- offer examples of science involving observations as well as experiments; field work, computer modeling, invention, and laboratory work;
- depict science as collaborative and interdisciplinary; and
- draw parallels between how the scientific team approaches a research project and how students conduct investigations.

The multidisciplinary project on which the film is based involves scientists in geology, geophysics, geochemistry, paleoclimate, and meteorology to study how the Tibetan Plateau formed geologically and how this massive landform affects climate and weather in its region and around the globe. The film shows glimpses of this science as the scientists discuss their questions and give synopses of their investigations, but more importantly it takes viewers on a journey to the field, laboratory and conference room to observe the scientists planning, reading, taking samples and analyzing them, building instruments and computer models, traveling, arguing about their ideas and enjoying collaboration. Through this insider's view, students see that science is a human process for constructing knowledge and gain appreciation of its everyday workings. Although the research project is discipline-specific, the film's emphasis is not; it can be used in any science course, not just Earth science.

The film was conceived by one of us (Laursen) and written and directed by Laursen and filmmaker Roslyn Dauber. Teacher input was critical in refining the film and making it interesting and visually attractive to students. It is distributed via DVD at workshops and screenings so that educators can experience the film and see how to use it. A website provides support materials and ideas for using and assessing the film.[1] At twenty minutes, the film can be shown and discussed in a single class period, leaving time for announcements and other class activities too. Responses from a subset of DVD recipients indicate that the film has been effective with a wide range of audiences: school students from grades 6 to 12, undergraduates, teachers and public audiences, in classes ranging from middle school Earth science to high school biology to college courses for non-science majors, and including honors courses and courses for English language learners. More details on the development of the film are available elsewhere (Laursen & Brickley 2010).

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[1] http://cires.colorado.edu/education/outreach/TibetOutwardUpward/

3.2. Evidence of the Film's Impact on Viewers

To support classroom educators in using the film, we developed a three-question pre/post writing activity that could be used to assess students' prior ideas, help them articulate their ideas, and guide class discussion. Prior to viewing the film, students were asked to draw or describe in writing "a scientist doing science." After viewing, they were asked to describe something that surprised them or gave them new insight about doing science. For the third question, also completed after viewing, students compared and discussed two diagrams representing the scientific process.

This worksheet also served as a pre/post assessment of the film, as we solicited teachers to send us classroom sets of anonymous student worksheets for analysis. A total of 350 student worksheets received from ten teachers were analyzed, focusing on the pre-screening question (Q1) and the first post-screening question (Q2). Students' verbatim answers were inductively coded into several themes that represented the core idea of the response; some student answers included multiple themes and were coded for each. Analysis methods are described in greater detail by Laursen and Brickley (2010).

A total of 545 ideas were coded in the responses to Q1. The most common theme in students' prior notions about science relates to chemistry or laboratory science: mentions of chemistry or mixing chemicals, and drawings of laboratories equipped with flasks and beakers, constituted 43% of student responses. The second most common theme, at 19% of all responses, addresses scientists' appearance, most often through eccentric outfits, crazed expressions, and Einstein-like hairdos. Discussion of experiments, the scientific method, and societal applications of science, made up the remaining three predominant themes. Overall, students' prior knowledge as seen in these responses is stereotypical and emphasizes laboratory disciplines and personal traits of scientists. These findings align very well with that seen in earlier studies using the Draw-A-Scientist Test (DAST) (Chambers 1983; Finson et al. 2002; Sjøberg 2000).

Analysis of student responses to Q2 yielded 421 distinct ideas, coded into eight separate themes. Because this question asked students what "surprise" or "insight" they gained from the film, these responses clearly indicate explicit student learning—new or altered ideas of which they are consciously aware. In comparing students' pre- and post-film responses, some responses directly show a change in a particular student's ideas. The change in the nature and distribution of ideas across the sample as a whole demonstrates these shifts on a larger scale.

Seven of the themes indicated "learning about science" and one reflected "learning science." The distribution of these student responses across the eight themes is shown in Figure 1, where each bar is labeled with the theme nickname and a brief definition. The first theme seen in Figure 1, "Science," accounted for 14% of student responses and included student reports of learning new scientific content. Most of these mentioned the collision of two tectonic plates that caused the uplift of the Tibetan Plateau, an idea demonstrated in an animation shown twice in the film. Other students commented on how the scientists analyzed rocks to determine the composition of ancient rainfall (as reflected in the isotopic composition of sedimentary carbonate minerals). While teaching geologic concepts was not the aim of the film, it is gratifying that students did in fact absorb some of the scientific "big ideas" depicted.

The other seven themes accounted for 86% of student responses, and all addressed some aspect of scientists' mental, social, and professional activities. Students reported new ideas "about science," including the nature of work as a scientist, how complete data collection is carried out, the background research and understanding behind good scientific questions, and the necessary collaboration between scientific fields. We categorized student comments under the following subjects.

- *Where:* Scientists travel to do their work, work outside.
- *Method:* How much work is involved; how samples are taken; details, organization, time.
- *Collaboration:* Collaboration of many different types of scientists from different specialties or countries; working together as a team; argumentation and discussion; friendship.
- *Fun:* People having fun, enjoying their work, being imaginative and creative.
- *Equipment:* Engineering, invention of unique equipment.
- *Questions:* Specific reference to science as a process to answer any question.
- *People:* Who is doing science? Observations on gender, race, nationality of scientists; scientists' dress or appearance.

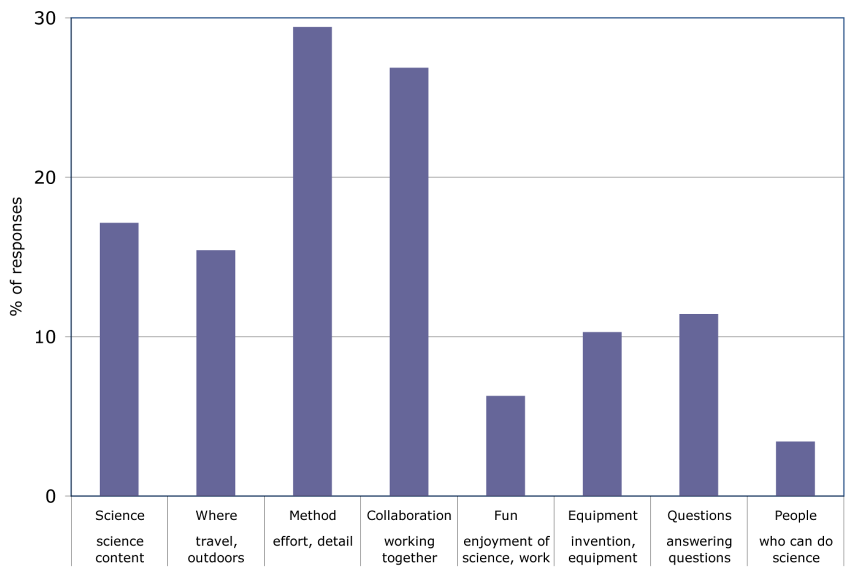

Figure 1. Distribution of 421 coded student responses to Q2 across eight themes.

Among comments in the category "Method," students remarked on the level of effort and care they saw in the film: "I did not know scientists took so many samples of rocks, dirt, sand, etc." Others reported changes in a view of science that emphasized laboratory work to incorporate field work and observational methods: "They don't just mix stuff.... They collect things for evidence." A smaller category, "Questions," gathers student observations about science as an organized process to find an answer to a question, an idea noted specifically by multiple speakers in the film. Both of these categories reflect more complex understanding of scientific methods than do student comments on the pre-film question Q1.

"Collaboration" was another striking aspect of the film for many students. They commented on the numbers of scientists involved and their interactions, and how people with different types of expertise could come together to solve a challenging, inherently interdisciplinary problem. This insight shows a change in students' notions of scientists as loners, a perception that was evident in their responses prior to seeing the film, and documents their insights about why scientists might collaborate.

Comments coded under "Where" reflect students' surprise that scientists could travel to other countries to do their work and could spend time hiking and working outdoors, not just inside. Many students were also struck by a segment of the film that showed a laboratory where new equipment was invented to make a specific measurement. The scientist on camera described ordering parts from catalogues and putting them together "in a way no one has ever done before, like Tinker Toys," an idea that clearly intrigued students. Both of these themes document a broadening of student notions of science to include not only laboratory work but field work and invention or engineering.

Comments gathered under the theme "Fun" reflect students' surprise that the scientists in the film enjoyed their work and being together, even though it was also evident that they worked hard. The theme "People" documents shifts in students' notions of who can do science: scientists are not all white, male, or American. They are people who can wear hiking clothes instead of lab coats and seem pretty normal. As one student mused, "There are people who are scientist[s] but aren't totally wack."

In sum, comparison of students' pre- and post-film responses shows direct evidence of changes in their ideas about who scientists are and what they do. Students take away new ideas from the film that contrast with their prior knowledge, counter common stereotypes of science and scientists, and broaden their notions of the scientific method. These messages are well aligned with the goals of the film and with national and state standards on learning about science.

4. Conclusion

As one of our student respondents wrote, "A scientist has many things to do." Indeed—so it is worth our while as EPO providers to choose our EPO activities to have the maximum impact possible. We argue that scientists can have the most positive effect on public understanding of science if they explicitly focus their EPO efforts on helping people understand the nature and practices of science. Such efforts are most effective when they are also grounded in the research on how people learn and responsive to the needs of the audience under consideration. We have provided examples of the kinds of activities that meet these goals and shown evidence that they are effective.

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copy of the DVD for educational use, please contact author Laursen. We will provide copies at no cost while grant funds permit, and for the cost of postage thereafter, as long as supplies last.

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