Focusing the Camera Lens on the Nature of Science: Evidence for the Effectiveness of Documentary Film as a Broader Impacts Strategy

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Abstract: Scientists' involvement in education has increased in recent years due to mechanisms such as the National Science Foundation's "broader impacts" expectations for research projects. The best investment of their effort lies in sharing their expertise on the nature and processes of science; film is one medium by which this can be done efficiently. In this article, we illustrate this approach through the development of *Upward and Outward: Scientific Inquiry on the Tibetan Plateau*, a twenty-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. Evidence gathered from pre/post classroom assessment responses by 350 students in grades 6-14 indicates that students absorb a variety of messages about the intellectual and social processes of science. These ideas contrast with their prior knowledge, counter common stereotypes of science and scientists, and broaden students' notions of the scientific method. The film aligns with national and state standards on scientific inquiry and the nature of science.

Keywords: broader impacts, documentary film, process of science, nature of science, outreach

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Introduction: Scientists' role in modeling inquiry

Leaders in U.S. science and education have called for scientists to participate in improving public understanding of science (Alberts, 1991, 1993; Bybee, 1998; Colwell & Kelly, 1999; Dolan, 2004; Fraknoi, 2005; Alberts, 2009; Obama, 2010). U.S. federal agencies that fund scientific research have provided incentives or stated expectations that scientists contribute to science education and outreach. For example, NASA's Science Mission Directorate requires that all missions have a "robust and substantial" commitment to education and public outreach activities (NASA, 2010, p. 1). In reviewing research proposals, the National Science Foundation weighs the "broader impact" of research—which may include activities to educate and inform students, teachers, policymakers or the general public (e.g., NSF, 2003). We refer to these activities collectively as education and outreach (E/O), following Franks et al. (2006), where education is the teaching and learning of knowledge, skills and cultural beliefs through formal (in school) or informal (self-directed, out of school) activities. Public outreach activities generate awareness and interest, and may also support education.

These activities are motivated by concerns about public understanding of science. A majority of Americans are interested in science, but "do not give correct answers to questions about basic factual knowledge of science or the scientific inquiry process" (National Science Board, 2010, p. 7-4). Widespread misconceptions about the nature of science and scientific knowledge contribute to contention rather than informed debate over issues such as climate change, stem cell research, and the teaching of evolution in schools (McComas, 1996). School textbooks may reinforce these myths by portraying “the scientific method” as a standardized, linear, four- or five-step process, in contrast with the complex, nuanced, and question-driven process described by scientists (Reiff et al., 2002; Harwood et al., 2002). Such portrayals address neither the inherent uncertainties in scientific knowledge, nor the iterative and social construction of that knowledge. These notions become problematic when they lead to over-reliance on science to provide definitive answers or, conversely, to loss of confidence in science as never getting anything “right."

Many people also hold stereotypes of scientists that may interfere with their understanding of science or their beliefs about its usefulness or reliability. One tool used to measure these ideas is the “Draw a Scientist” test (DAST) (Chambers, 1993; Finson, 2002; Sjøberg, 2000). Children's drawings made for the test often portray brainy, anti-social geeks who work alone in labs and explode things; these widespread views are corroborated by data from surveys, essays, and interviews (Finson, 2002); adults' ideas—including teachers’—are substantially the same (Rahm & Charbonneau, 1997; Barman, 1999; Cady & Reardon, 2007). Evidently, people’s notions of scientists do not evolve greatly over time despite education and other life experiences. These stereotypes are robust in society too: study results are largely unchanged over the decades (Mead & Metraux, 1957) and startlingly similar across cultures (Sjøberg, 2000). One small bright spot: children draw fewer representations of Frankenstein today than in 1957.

Goals for science education that address these perceptions of science are well articulated in documents such as the National Science Education Standards (1995; see also American Association for the Advancement of Science, 1990). The standards identify three broad learning goals for all students:

1) to learn science—the big ideas and central concepts of science. For example, plants grow by using energy from the sun to convert carbon dioxide from air into biomass.

2) to learn how to do science—the skills and habits of mind required to conduct an investigation. These include both practical skills (measuring, graphing) and intellectual abilities (controlling a variable, interpreting a negative finding).

3) to learn about science—the understanding that science is a human activity and a method of constructing knowledge. For example, scientists hold particular standards for which evidence and methods are acceptable, which may differ from those of other disciplines.

These two latter goals emphasize the scientific process for building new knowledge as distinct from the existing facts and concepts of scientific knowledge stated in the first goal. But these goals are related: as a recent report notes, "Developing deep understandings of science requires understanding the nature of scientific explanations, models, and theories as well as the practices used to generate these products" (Bell et al., 2009, p. 275).

In practice, most classroom time and textbook space address Goal #1, the big ideas of science. Goal #2, learning to do science, is most often addressed through laboratory work or hands-on inquiry. The poor state of laboratory instruction (Singer, Hilton & Schweingruber, 2002) and the growing use of inquiry curricula and instruction give reason for both despair and hope that this goal can be achieved. Goal #3, learning about science, is rarely addressed explicitly. Many instructors assume that students will glean these ideas as a side effect of laboratory work, albeit with little evidence to support that belief.

Goals #2 and #3 are related but distinct: Students' ability to perform an investigation should be better if they recognize general qualities of a good or bad investigation. But it is challenging to abstract from a particular laboratory experience to general understanding. Even if students can interpret what they have learned when a white powder does *not* react with hydrochloric acid, this seldom yields broader understanding about negative evidence that can be applied to other problems. These are hard topics for teachers too. Few science teachers have a chance to develop personal knowledge of the process of science by conducting research first-hand. In their own schooling, most experienced fact-packed lecture courses rather than deep engagement with gathering, interpreting and communicating about scientific evidence. Teachers are thus at a disadvantage in teaching about the nature of science, and few curricular resources directly address these ideas.

Given these gaps in understanding and in school programming, it is especially crucial for scientists to share their expertise on the nature and process of science. These concepts are not discipline-specific: every scientist is an expert who can offer rich examples of science at work in her own field. We have elaborated this point elsewhere (Laursen, 2006; Laursen & Smith, 2009; Thiry, Laursen & Hunter, 2008). Here, we describe one way that scientists and their collaborators can communicate the nature and process of science to students and teachers, through an educational documentary film for secondary students and teachers. Film can reach sizable audiences in and out of classrooms and leverages scientists' time efficiently. As curriculum, it is a flexible, useful and familiar tool for teachers. We describe the design and use of the film, offer evidence about what students learn from the film, and suggest lessons learned here that can be applied to other science E/O efforts.

The documentary film and its development

To address the paucity of classroom materials available for teaching about science, Laursen and colleagues developed a short educational documentary film and distributed it to secondary school educators. Funded as a "broader impact" component for a large collaborative 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
- Draw parallels between how the scientific team approaches a research project and how students conduct investigations.

The educational documentary film, *Upward and Outward: Scientific Inquiry on the Tibetan Plateau*, is centered on a multidisciplinary, collaborative, research project to study the geologic uplift of the Tibetan Plateau and its impact on atmospheric and climate processes. The research team includes scholars and students in geology, geophysics, geochemistry, paleoclimate, and meteorology. They use geophysical methods, mapping, and age dating of rocks to understand how and when the Plateau grew, both rising in altitude and expanding to the north (e.g., Molnar & Stock, 2009; Dayem, et al., 2009). Isotopic analysis of basin sediments and meteorological modeling are used to decipher past changes in wind and precipitation patterns that occurred as the Plateau grew and began to interact with the jet stream (e.g., Roe, 2010; Dayem, et al., 2010). A critical intellectual step is to compare the timing of these events: Can these regional climate changes be linked to the Plateau's upward and outward tectonic growth? (Molnar, 2005)

Rather than explaining the scientific content of the research, however, the film focuses on the process of science as seen through this project. Thus it is appropriate for any science class, not just Earth science. Viewers follow the international team of scientists as they work in the lab and in the field, build new instruments and computer models, travel to China for field work and conferences, argue about their findings, and enjoy collaboration and conversation. In gaining an insider's glimpse into both the intellectual process of scientific inquiry and the everyday social and professional activities of science, students learn how science is a human process for building knowledge, not just a body of fact, and they come to see scientists as real people.

Originally targeted to students in grades 8-10, the film has proven effective with both older and younger students, from sixth-graders to undergraduates and teachers.

At 20 minutes, the film can be readily screened and discussed within a single class session. A web site (http://cires.colorado.edu/education/outreach/TibetOutwardUpward/) provides teachers with a description of the film and its links to the inquiry standards, suggested pre/post writing prompts, discussion questions, teaching tips, and background on the film's educational and scientific content and students' likely prior conceptions. This is not a prescriptive lesson plan, but a set of practical ideas to help teachers place the film in their own curricular context, adapt its use to different age groups and learning objectives, and foster student engagement with its ideas. The film does not explicitly espouse inquiry or any other pedagogical approach, but by showing how scientists think and work, we hope to encourage students and teachers to take a similar investigative approach to their classroom work, in line with Bowers' (1996) admonition:

> Real science whether in the laboratory or the classroom depends substantially on the application of good scientific process. By scientific process I do not mean the famous four steps in the scientific method that are drilled into the heads of children from Grade 3. Instead I mean the real scientific skills of investigation, critical thinking, imagination, intuition, playfulness, and thinking on your feet and with your hands that are essential to success in scientific research.

Constructing the film required the scientific, educational and artistic expertise of many contributors. Funded through a National Science Foundation grant to the research team, the size and scope of the research project (five years, seven PIs, $2.9 million budget) warranted a significant material commitment to a specific "broader impacts" component. The lead investigator publicly stated his belief that including the film in the grant proposal as a specific E/O effort was a positive factor in receiving an award after a previously declined proposal.

The concept was developed by author Laursen, an outreach scientist with a Ph.D. in chemistry and experience in inquiry-based teaching and teacher professional development. Roslyn Dauber, an independent documentary filmmaker, contributed her technical and artistic expertise; her background in science policy and interest in science were also assets. Together Laursen and Dauber developed the story line and script. Scientific team members gave on-camera interviews and laboratory tours to explain the project and describe the scientific process; several provided advice, graphics, animations, and still images. One graduate student carried a video camera to China and shot footage for the film; another shared stunning photographs from his time in the field.

Laursen worked with individual scientists and attended team meetings to learn about the research. When a rough cut (draft) was ready, she screened it to gather scientists' input. It was important to us to get the science right, but we experienced a steady tension between accuracy and simplicity. Some scientists felt the film offered too shallow a treatment of their subject, and indeed it was tempting to explain interesting details about the study or its methods. We found it essential to frequently restate our goal to communicate about how science works, and to clarify why that was important. As the film progressed, we critically analyzed each cut for which elements best accomplished this goal within our rigorous length criterion of 20 minutes.

Local teachers were recruited to respond to an early cut of the film; it was substantially revised based on their feedback. For example, based on concerns about visual appeal to students, we added high-energy production features: animations, rapid cuts, mood-setting music, and a whimsical opening using vintage footage of scientists. With help from the director of a summer science camp, we incorporated footage of high school students doing science to more explicitly link the processes that scientists use in research and students use in the classroom. These efforts paid off, as one high school teacher reported: "It was a perfect length, and [the] music and changing scenes kept their attention." Thus teacher ideas were critical in helping to improve the film; the features they suggested are also those shown by research to foster greater attention and learning (see Mares, Cantor & Steinbach, 1999; Fisch, 2004).

Classroom reach and impact of the film

Distribution

Based on teacher input and our experience in K-12 classrooms, we produced the film as hard-copy DVDs. Most teachers have access to and are comfortable using a classroom video player; fewer feel well prepared to use the Internet in teaching (Russell, et al., 2003; National Center for Education Statistics, 2000). We considered online distribution but were concerned that the large file size required would tax school bandwidth: one failed download would deter a teacher forever, compared with the robust and familiar technology of a DVD player. Moreover, schools with more minority and/or low-income students tend to have poor access to classroom technology and make less use of it (National Center for Education Statistics, 2000; Owens, Song & Kidd, 2007). Cost posed an additional practical issue. Background music was chosen from a library of low-cost music clips offered by a licensing service; the fees for music rights are based on the number of viewers reached. The fees for web dissemination are high because a web-based movie hypothetically reaches all six billion people on the planet.

We distributed the film primarily through in-person contact, giving DVDs to educators who attended a screening with the reasoning that this would increase classroom use compared to unsolicited mailings or conference booth giveaways. We showed and discussed the film at teacher workshops, education conferences, schools, and public science events, and gave copies to school district science leaders and educators from higher education, informal science, and research organizations who lead in-service courses for K-12 teachers. Through these colleagues the film penetrated entire school districts and reached workshops and conferences around the U.S. and in South Africa and Australia. After showings to scientists at conferences and local laboratories, some took DVDs for their own outreach work or for friends and relatives who were teachers. Other educators requested the film via our web site. DVDs packaged in a hard plastic case could be mailed by applying an address label and fourth-class postage. At screenings and on the web site, we invited teachers to share their students' responses to the film. Author Brickley, a science educator and professional developer who used the film and distributed it to teachers, analyzed the student responses thus gathered; this analysis is discussed below.

Because we distributed the DVDs in person, we could track their distribution. To date, some 600 copies of the film have been distributed. Of these, over 60% went directly to educators: 31% to classroom teachers, 23% to professional developers who work with teachers, and 8% to college science instructors, including those teaching pre-service teachers. The other copies were distributed by the research team members to similar audiences, but we did not document their individual recipients.

Teacher response and classroom use

Based on our observations at screenings, anecdotal evidence, and some evaluation data, it is evident that seeing and discussing the film themselves helped teachers understand its messages and recognize potential classroom uses. Indeed, we found the film to be particularly effective to kick off a session on teaching science through inquiry in stand-alone workshops or multi-day professional development courses. Seeing scientists in action gave teachers a model for how their students could think and work like scientists in the classroom: posing questions, gathering evidence, and interpreting it; collaborating and making and critiquing arguments about their conclusions. Framing classroom inquiry as analogous to scientific research seemed to appeal to teachers as science professionals and could overcome some resistance to inquiry as the latest ed-school fad.

Teachers also gained enhanced understanding of the scientific process themselves. In discussion after a screening, teachers consistently commented on collaboration as an aspect of the film that was surprising to them. They remarked on the film's portrayal of how diverse skill sets and perspectives helped to solve hard problems and how articulating ideas aloud to others could refine and strengthen them.

They noticed that the scientists seemed to enjoy working together. One middle school teacher wrote:

> I really like the collaboration aspect shown in the video—lots of different kinds of scientists from lots of different areas and institutions. The scientists all look like real people, some in the lab and some in the field. It makes science look fun and exciting—which it is, but I think with all the testing we do we are taking the fun out of it!

A district science curriculum director emphasized why it was important to teach students about how science works, referencing parental skepticism of science taught in schools:

> As a leadership group, we have been talking about the importance of teaching the nature of science and having our students understand the work scientists do. More and more we are faced with students requesting to opt out of certain parts of the curriculum (most often evolution during biology, but this year also diseases and climate change). We need to educate our students to think critically about the information they come across, whether in class, online, [or] in the movie theatre.

Teacher comments also elucidate how the film reached student audiences. At closed-enrollment workshops where we could gather evaluation data, teacher responses to open-ended survey questions indicated their intent to make "immediate classroom use" of the film to "show what a scientist is" and "explain the scientific process." "It's so connected to what I am doing in the classroom now," wrote one. K-12 teachers reported using the film in biology, chemistry, Earth science, and general science classes across the middle and high school grades. "The video really opened their eyes to the many opportunities in the field. My 7th and 8th graders have a very narrow view of what you can do with what I am teaching them and how many jobs in this world are related to science," said one teacher. Higher education users were most likely to use the film in science courses for non-science majors or for pre-service teachers. "I reordered my class to start with a section on what is a scientist and what does it mean to 'do science' and an activity on observations and inferences. The video worked well [as part of this]," wrote one college instructor. Lesson ideas shared with teachers emphasized discussion, to foster learning through social interaction over the media experience (Kozma, 1991).

From teacher reports, we can estimate the number of students reached by the 600 copies distributed to date. Ten classroom teachers sent us a total of 350 student papers. Thus, for this group, each DVD reached 35 students on average in one academic year. This estimate is likely low, because teachers did not necessarily send student papers for all class sections that viewed the film. With the conservative assumption that only 50% of all DVDs distributed were shown to students, a total of 10,500 students (300 DVDs x 35 students) viewed the DVD in one academic year. The actual number of students reached will be much larger if teachers show the film in multiple sections, courses, or semesters, and use it again in subsequent years.

Evidence of student learning

Qualitative data were collected to assess student learning from the film. At teacher workshops using the film, teachers used a pre-/post-assessment tool that they could also use with students . While the main purpose of the assessment was to focus students' attention and foster classroom discussion, teachers were also invited to return classroom sets of anonymous student papers, which we used to assess the impact of the film on students. To acknowledge their help, participating teachers received a $10 gift certificate to an online bookstore. We asked teacher to conduct the assessment as modeled in the workshop. Before watching the video, students were asked to "draw or write a paragraph describing a scientist doing science." (Question 1). Following the video, students were asked to respond to two more questions:

2. Describe something that surprised you in the DVD or gave you a new insight about doing science.

3. Study Figures 1 and 2 on the next page, which show two different views of the scientific process. What elements of each did you see in the film? Which version do you think matches the film best?

For Question 3, Figure 1 showed a mostly linear flow chart depicting the classic scientific method , similar to illustrations often found in school textbooks (Reiff, Harwood & Phillipson, 2002; Blachowicz, 2009) or in a simple internet query for "scientific method." It emphasizes the formation, testing and validation of hypotheses. Figure 2 showed the "inquiry wheel" of Reiff, Harwood and Phillipson (2002), a model that was developed from interviews with scientists and that depicts a less linear, more iterative view of science (see also Harwood, 2004). This model includes activities such as observing, investigating the known, reflecting on findings, and communicating results, in addition to hypothesis formation and testing. The assessment, with images, is available on our web site (http://cires.colorado.edu/education/outreach/TibetOutwardUpward/images/Student Work Survey.pdf)

Altogether, 350 student responses were received from ten different classroom groups, most from Maine and Colorado: five groups of middle school (MS) students totaling 151, four groups of high school (HS) students totaling 171, and one group of 28 undergraduates (UG). Middle school students included students in grades 6-8 taking Earth science or general science. High school students were a mix of Earth/Space science students and biology students in honors, Advanced Placement (AP), and mainstream classes. The undergraduates were taking a natural science course for non-science majors. In this analysis, we have grouped the undergraduate students with the high school students. To reduce the reporting burden on teachers who voluntarily administered the assessment and mailed student responses, and to maintain strict student anonymity, no data were collected on class sizes, content coverage, time of year, or on student gender, ethnicity or socioeconomic status.

Methods of analysis

Using thematic content analysis (Libarkin & Kurdziel, 2002; Smith, 2000), student responses to each of the three questions were inductively coded into common themes. Specific words, phrases or items included in the drawings were the markers for certain codes. Others were defined by the central idea presented. Some students' responses were coded with multiple themes, therefore when reporting counts we refer to the number of "ideas" or "observations" rather than the number of students discussing a particular issue.

Five dominant themes emerged from analysis of Q1 and are listed in Table 1, below. This first question was similar in nature to the commonly used Draw-A-Scientist Test (DAST) of Chambers (1983), but broader themes and themes based on word cues or descriptions were used rather than the specific criteria used by Chambers or the Draw-A-Scientist Checklist, DAST-C, developed by Finson, Beaver, and Cramond (1995). Question 2 asked students to describe something that surprised them in the DVD or gave them new insight into doing science. The eight dominant themes derived from coding are listed in Table 2, below. Question 3 was analyzed at a more basic level because many students did not completely answer the question as phrased. Most students did identify which diagram they thought was best represented in the movie. Responses were coded as selecting Figure 1 (Classic Scientific Method), Figure 2 (Inquiry Wheel), or both; student reasoning was not coded because it was seldom given in detail.

Once student responses were categorized by themes, we quantified the number of observations under each theme. One student paper may include multiple observations about several themes. Most responses were brief, averaging 1.2-1.4 distinct observations per student for Questions 1 and 2; high school and college students typically reported more observations than did middle students. Because Question 3 forced students to choose between two alternatives, we categorized only one observation per student in that analysis. Below we quote student comments as examples of the themes found in coding. We have corrected some grammatical and spelling errors that were distracting, but left others to preserve the authenticity of students' voices. Quotations are labeled with the writer's age group and science class.

Findings

Student prior conceptions

In classroom use, Question 1 served to surface student preconceptions before viewing the film. In our evaluation of the film's impact, we used it to ascertain that the prior conceptions of students about "scientists doing science" were in fact similar to those previously demonstrated in other DAST studies. Table 1 summarizes the five categories and proportions of student observations in each.

Table 1: Categories and Frequency of Student Prior Conceptions of Scientists, from 350 Student Responses to Question 1

Category	Description	Response type D=drawing, W=written	Number of observations	Percentage of all observations	Similar categories in DAST-C (Finson, Beaver & Cramond, 1995)
Chemistry/ Laboratory	Specific mention of "chemi-"; notion that science is done in a lab. Drawings of someone holding beakers, flasks, etc.	D & W	234	43%	Symbols of research, Scientists working in lab, Symbols of knowledge
Experiments	Includes the word "experiments"—all verbal. Many double-coded with Chemistry/Lab or Observations	W	70	13%	
Classic scientific method	Includes words such as "observations," "hypothesis," "collecting data," "conclusions."	W	92	17%	
Appearance	Mostly drawings: wild hair, crazy expressions, Einstein-like images. Also comments on appearance. Does not include lab coat and glasses which are routine in "lab safety" education.	D	104	19%	Facial hair, Mythic stereotypes, Open comments on appearance
Science in society	Connections of science to other subject areas; the broader scope of science and its role in society, e.g. medical cures, new chemicals, use of mathematics.	D&W	45	8%	Relevant captions (formulae, idea bubbles)
Total			545	100%	

While based on a coding scheme that was independently developed, our results fell largely in line with the stereotypes expected from DAST studies. Of the 350 students surveyed, fully two thirds identified scientists doing science with some feature of a "lab" or "laboratory," accounting for 43% of observations. Many of these were drawings of lab tables and equipment; a written example is:

> Scientists think of expirements (*sic*) to do and create hypothesis's (*sic*) for what they believe will happen. Then they do the experiment and record observations. When the lab is over, they go over their notes. The experiments they do are based on what they want to learn. (HS AP biology student)

Another 19 percent of the observations noted the unnatural appearance of scientists (e.g., wild hair). Middle school students (78%) more often identified science through lab equipment while high school and college students (37%) more often described the scientist's appearance. Drawings illustrated images like that presented in this student description:

> Scientists wear a big white lab coat, and they have goggles around their head. He has kind of curly/poofy white hair and glasses. He wears a suit underneath his lab coat. He has on fancy black laced up shoes. He's really pale looking and very old. Big, bushy eyebrows and mustache maybe. (HS chemistry/biology student)

Another 13% of observations included the word “experiment/s” in the description, presenting experiments as a way to learn about the unknown: a trial with unexpected outcomes. Use of this word was often nonspecific, as in this student response:

> When scientists do science I think that sometimes they don't know what they are doing and they are trying new stuff at the same time. So they experiment with things. (6th grade science student)

Other observations were more detailed, such as: "A scientist doing science is when someone is experimenting different hypotheses and theories" (HS Earth/space science student). Seventeen percent of observations included some feature of the classically taught scientific method (e.g., observe, hypothesize, collect data). Some classes had probably covered this recently, as student descriptions were presented stepwise and described a procedure akin to the classical textbook presentation.

> A scientist when doing science has many things to do. They first come up with why they are going to do that topic. They then gather data/info and come up with a hypothesis (Ex: my guess is the experiment will work without glitches.) They will do the tests/trials of the experiment more than once or twice. They will have a conclusion about their topic. (MS science student)

A small proportion (8%) of student observations were less stereotyped, making broader connections to the role of science in society and its links to other areas of research (i.e. medicine, use of mathematics). Some observations in this category were general, like this one:

> Science is whatever you decide to apply working and validated logic and concepts to answer or explain a question. A scientist is simply someone who decides he or she should ask the right questions to get the temporarily correct answer. (HS Earth/space science student)

Others mentioned different fields or applications of science, as this sixth-grader shared:

> There are lots of different kinds of scientist[s]. Some of them mix things like chemicals together. Like Pharmists (*sic*), I consider them scientists. They mix different pills and medicines together. Some look at the earth and study the land and look at dirt and soil and see how it forms. They also study things like solids, liquids, and gases. (6th grade science student)

These results set the stage, identifying our audience as students who hold a largely classical and stereotypical view of science as laboratory work done in seclusion by out-of-the-ordinary individuals. They are somewhat influenced, at least in terminology, by an introduction to the classical scientific method and to experimentation as a major way of doing science. Specific science topics, perhaps recently studied, appear in some answers.

Student change of conceptions

In their responses to Question 2, completed after viewing the film, students showed a notable change in their ideas, giving answers that exhibited a broader view of scientists doing science. The question asked them to "Describe something that surprised you in the DVD or gave you a new insight about doing science." In classroom use, this question aimed to have students reflect individually on what they learned and generate ideas for class discussion. Of the eight themes identified in coding, seven indicated that students were learning something "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. Their language and remarks can sometimes be tied to very specific scenes or dialogue in the film. These themes and their frequency in student papers are detailed in Table 2.

Table 2: Categories and Frequency of Changes in Student Conceptions of Science and Scientists, from 350 Student Responses to Question 2

Category	Description	Number of observations	Percentage of all observations
Learning about science			
Method	How much work is involved; how samples are taken; details, organization, time	103	24%
Collaboration	Collaboration of many different types of scientists from different specialties or countries; working together as a team; argumentation and discussion; friendship	94	22%
Where	Scientists travel to do their work, work outside	54	13%
Question	Specific reference to science as a process to answer any question	40	10%
Equipment	Engineering, invention of unique equipment	36	9%
Fun	People having fun, enjoying their work, being imaginative and creative	22	5%
People	Who is doing science: observations on gender, race, nationality of scientists; scientists' dress or appearance	12	3%
Subtotal, learning about science		361	96%
Learning science	Science content learned, esp. formation of Plateau by colliding plates, learning Earth's history from rocks	60	14%
Total		421	100%

Nearly a third of all students (representing 24% of all observations) expressed surprise at how science was carried out in the film, through shots of the field work, labs, samples, and explanations of what was done to gather evidence. Many students noted the number of samples collected, like this student: "I did not know that scientists took so many samples of rock, dirt, sand, etc." (HS Earth/space science student) Another shared how his or her ideas had changed about what scientists do in a lab, "They don't just mix stuff.... They collect things for evidence. " (6th grade science student). Some students gained a better understanding of what it means to form a hypothesis: "It is surprising that there is a lot of reading and research involved in making an hypothesis (*sic*)" (HS Earth/space science student).

Middle school students were most struck by seeing scientists working together as a team, with 31% of 151 students in this age group noting collaboration. Nearly a quarter (24%) of the high school and college students were also struck by the collaboration they witnessed in the video. These numbers suggest that neither age group had previously thought about scientists working together, and that the film challenged a common idea of scientists working alone.

> There were different scientist[s] sharing different information w[ith] each other. Also there are field [and] indoor scientist[s]. (MS Earth science student)
>
> I'm surprised that scientists like working together. It seems like they would disagree and argue about everything. But I guess that just matters on who is in your group. (HS biology student)

Another group of responses described science as "a way to answer any question.” Ten percent of responses noted this idea, showing a widening view of how science is a thinking process and not just subject matter. This point was made explicitly in the film multiple times; stated by one scientist near the end of the film, the idea seemed to grab a subset of students. Some understood the process explicitly, as in this quotation:

> If you want to know something and you go out to find the answer to that question, you are a scientist. (HS Earth/space science student)

Others took the idea generally, and may still hold some misconceptions, like this middle school student: "That if you can find something that you don't know what it is and you find out, that's science." (MS science student)

The film showed scientists traveling the world and working in the field. This aspect of science surprised students and was noted in 17% of the observations. Their image of scientific work was expanded beyond lab work, as this middle school student expressed: "Something that surprised me in the DVD is when the scientists travel and not only stay in the room and work, they go to other states (*sic*)." Similarly, a high school student mentioned "That science isn't all about being in a lab, but it's everywhere." (HS chemistry/biology student)

We were also struck by the frequency of student comments relating science to engineering and technology. Ten percent of observations described a new realization that scientists sometimes need to build or invent the equipment to make measurements. These most likely stemmed from one film segment in which a researcher enthusiastically described his laboratory. His research team had invented a scientific instrument and built it from "catalogue parts, like Tinker Toys—putting them together in a way that nobody has ever put them together before," as he described it. Several student comments clearly refer to this segment:

> I was surprised that the instruments they used in the lab were instruments they invented. (6th grade science student)
>
> It surprised me that scientists invent new machines from catalogue parts so that they can do exactly what they want done. (UG natural science student)

Lastly, in addition to these themes that address learning about science, an eighth theme showed that students were also "learning science," gaining some understanding of the scientific content of the research study depicted in the film. While teaching scientific concepts was not a primary goal of the film, it is gratifying to know that students did absorb some of the concepts referenced. Fourteen percent of observations, representing 17% of students, commented on a science concept. Many of these responded to an animation, shown twice in the film, of the collision between the Indian and Asian tectonic plates, as in this example: "Something that surprised me in the DVD was how India was just pushing itself into Asia. It is cool that the Earth can actually do that and form new land." Other students responded to the idea that rocks can be used to diagnose past climate and conditions.

For the final assessment question, students were asked to study figures showing two different views of the scientific process. They were then asked to identify what elements of each they saw in the film, and which version they thought best matched the film. Many student responses were not complete, answering only a portion of the two-part question. This may be due to the wording of the question in two parts or to a need for more explicit class discussion of the figures. So, while we cannot discern entirely what ideas led students to select one figure or another, we do see a trend towards a view of science more consistent with that held by scientists and philosophers (Reiff, Harwood and Phillipson, 2002; Blachowicz, 2009). Over two thirds (69%) of students felt that Figure 2, the inquiry wheel, best matched what they saw in the film. Of the 20% who felt the film best identified with the classical scientific method, many mentioned the iterative nature of the diagram, understanding that scientists have to “go back” if they don’t answer their question the first time through. We interpret both types of responses as reflecting modest increases in the sophistication of students' understanding of the scientific process.

Another 9% of students did not select either diagram and seemed not to comprehend what was being asked. Not having seen either diagram prior to the survey, it’s possible that many were not sure of the meaning of the arrows and shapes showing the different processes. Indeed, one sixth-grade teacher reported that her students had difficulty with this question. Next time, she planned to share and discuss the diagrams before showing the film, to prepare students to spot their components.

Discussion

Student responses to the film align with its goals

A basic but important interpretation of these data is that students take away messages from the film that are well aligned with its intentions and that reflect real changes in their ideas. Nearly 90% of student responses to Question 2 can be classified as "learning about science," illustrating new or altered ideas about how science works. Students gain insights into the methods of science—the effort and number of samples required, the need for team members with varied expertise—and the creativity it requires. They see science as a type of work done by real people, perhaps even themselves in the future. They respond to the film's strong and deliberate framing of science as question-driven, and to the people they see in the film as different from stereotypes they have encountered earlier. In class discussion, they encounter additional ideas that may reinforce or challenge their own.

The film set out to address students' views of both the intellectual and social processes of science. The seven themes within the broad "learning about science" category can be roughly grouped into these subsets: the themes we nicknamed as Methods, Questions, and Equipment (Table 2) are more clearly related to the intellectual process of science, while themes entitled Collaboration, People, and Fun directly address the social processes. The theme we nicknamed Where includes elements of both: comments that some scientific investigations were conducted by making observations in the field, rather than by experiments in the laboratory, reflect understanding of an intellectual approach; while other comments noted that "scientists can work outside." Because the former idea dominated, we include this category with intellectual processes. Using this grouping, 55% of all student comments address the intellectual processes of science, and 30% address social processes; the remaining 14% address science concepts.

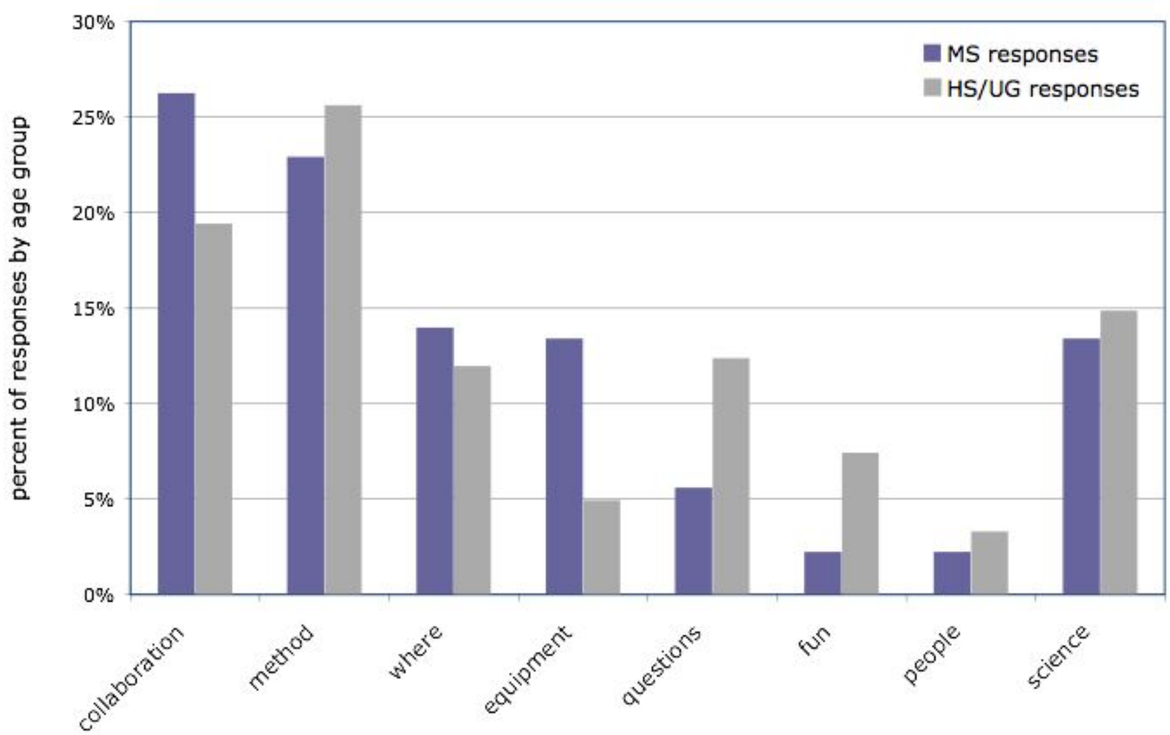
Moreover, these ideas expressed in student responses reflect actual changes in students' ideas and beliefs. Question 2 was deliberately phrased as "What surprised you or gave you new insight…?" in order to probe for changes in students' conceptions. Indeed, student responses often stand in direct opposition to the initial ideas they articulated or sketched for Question 1: scientists are cooperative rather than solitary; interesting rather than "dorks"; not all male, white, or American. While faint praise at best, they reflect genuine changes in thinking: "There are people who are scientists but aren't totally wack." Science can be done in the field as well as the lab; science involves using cool equipment and inventing it oneself. "Something that gives me a new insight on science is that it involves creativity and imagination. When I think of science, I don't think of having to use your imagination and creativity!"

Responses to Question 3 are best read as reflecting a generally broadened view of the process of science. Some students detected a logical progression of hypotheses and observations in the film and thus preferred the linear scientific method diagram. A larger group recognized elements of a more complicated scientific process, as suggested by the inquiry wheel diagram. Both can be argued to be valid answers, but the choice forced by the phrasing of the question likely obscured students' real beliefs. Class discussion or teacher statements may have steered students toward the wheel diagram– in part because teachers' views too were expanded by the film and discussion, consistent with the film's educational goals. In teacher workshops, we find that the inquiry wheel provides teachers with useful language by which to link the classic scientific method commonly portrayed in textbooks with a broader, more complex portrayal of science as conducted in practice. The results from Question 3 are less useful for understanding student impact than are those from Questions 1 and 2, but it was pedagogically useful in generating discussion and encouraging students to consider aspects of both diagrams shown in the film.

<u>Developmental differences in student responses</u>

We analyzed student responses by broad grade level, separating middle school from high school and college students. The data are plotted in Figure 1 using the same categories listed in Table 2; they reflect modest variation of responses by grade level.

Figure 1: Age group differences in student responses



For example, middle school students more often remarked on certain social processes of science, such as collaborating and working outside. High school students and undergraduates more often called out the intellectual processes of science, noting aspects that were more abstract: methods that require effort and attention to detail, and the notion of science as answering questions. Middle school students' observations about investigations focused on pragmatic issues, such as the equipment that scientists used and invented.

These may reflect real age-based differences in what students know already, what they learn from the film, and/or what interests them. Middle school is when students are typically identifying their interest—or lack of it—in science-oriented careers (Tai, et al., 2006). Thus middle school students' interest in scientists' everyday work may reflect openness to viewing the scientists in the film as possible future selves, while high school students are more likely to have already self-identified as science-oriented or not. High school students were also more likely to note surprise that science was fun—perhaps reflecting greater prevalence at this age of a pre-existing expectation that it was *not* fun.

However, we also noted strong variations in the frequency of themes from class to class that likely reflect how teachers presented the film, their expectations for student writing, and the placement of the film within the overall course. This variability, and the fact that our sample of 350 students is gathered from only fifteen class sections taught by ten teachers, mean that we cannot reliably generalize about age differences in response. Still, it is clear that students across a wide span of ages, from Grade 6 to college, can extract meaningful ideas from the film that are developmentally appropriate and consistent with the messages we sought to communicate. The film appears to offer multiple access points for a range of student audiences.

Comparison with other studies

Prior research has examined how science and scientists are presented in the media to children and adults (Long & Steinke, 1996; Nisbet, et al., 2002, and references therein). Such studies document some of the media images that this film directly sought to counter—portrayals of scientists as eccentric and antisocial, isolated, and elite explainers of knowledge. These are broad surveys of what is distributed to media viewers, rather than how they react. Other studies have correlated public attitudes toward science with general media consumption behaviors, such as television-watching and newspaper-reading, but cannot trace the influence of any particular medium or program (Nisbet et al., 2002; Miller, 2001).

More targeted studies have sought to examine the impact of single science media programs by measuring varied outcomes for viewers, including understanding of specific science concepts (e.g., Smith & Reiser, 1997), interest in science (e.g., Mares, Cantor & Steinbach, 1999), attitudes and beliefs (e.g., Penn, Chamberlin & Kim, 2003), or emotions (e.g., Barbas, Paraskevopoulous & Stamou, 2009). For example, Fortner (1986) studied children's learning from a Cousteau Society documentary film about marine mammals using pre/post/delayed post tests. The treatment group viewed the film, while the comparison group viewed a teacher's presentation of the film script. Children randomly assigned to treatment and comparison groups remembered the material equally well, but attitudes were more positively affected by the film. Our study is unusual in focusing on understanding of the nature and process of science as the measured student outcome.

A recent report from the National Research Council points out, "Few studies speak to the impact of science-related [media] programs on the audience's understanding of science" (Bell et al., p. 275). Difficulties include determining whether the film reached its target audience, separating effects of the media program from the many other factors that influence people's ideas about science, and capturing data on impact from volunteer public audiences (Friedman, 2008; Von Secker, 2001). It is clearly easier to detect the impact of multiple episodes of a TV series like *Bill Nye the Science Guy* (Rockman Et Al, 1997, cited in Bell et al., 2009) than to assess changes due to a single viewing experience. One advantage in the present study over studies of broadcast media is that the main target audience can be identified and reached through their teachers.

This study does not purport to establish or test student ideas about the nature of science, nor to compare interventions for influencing these ideas. Rather, it offers evidence about the impact of an educational media product developed through a federally funded science E/O effort. The authentic assessment was provided as a teaching tool and used only secondarily for measuring impact. Our choices of sampling and data-gathering approaches were shaped by the project's goal to develop and distribute an educational documentary film, rather than to conduct research. These choices in turn lead to some limitations in the evidence: the sample is one of convenience, and data are lacking about factors such as student gender and ethnicity that are known to affect student responses (Finson, 2002). The immediate pre-/post-test design means that we do not know the longevity of the changes in student ideas documented. But by using our direct-to-teachers distribution approach, and by borrowing data analysis methods from educational research, we can collect data and draw conclusions about the film's impact on its end audience, secondary students. Thus this study is a rare example of how audience learning—not just providers' E/O activity or audience satisfaction—can be measured, and it offers a model for evaluating the impact of E/O efforts by research projects and institutions.

Conclusions and Future Directions

Many people have narrow or distorted views of science and scientists. These views will change only if they become aware of their own preconceptions and see alternate portrayals of science and scientists. Such experiences may be especially crucial for teachers, who are strong influences on students' perceptions of science and scientists but who seldom have opportunities to meet real scientists (McDuffie, 2001; Cady & Reardon, 2007). Using an NSF-funded research study as a vehicle for communicating broader impacts of the research, we developed a documentary film to offer alternative views of science and scientists and collected evidence that it helps to alter these perceptions. We believe the film was effective in accomplishing these goals because we drew on best practices from educational R&D to design and share the film. In particular, we:

- addressed a recognized gap in K-12 science curriculum materials
- communicated important ideas about how science works in an interesting manner, through the vehicle of a specific research study

- provided multiple points of access to these ideas for a wide range of audiences from Grade 6 to adults
- involved scientists in ways that were appropriate, comfortable and interesting for them, and that drew on their expertise
- collaborated closely with professional filmmakers to create a visually stimulating, technically superior product
- engaged teachers personally in both making the film and preparing them to use it in the classroom
- supported teachers through professional development and classroom materials
- fostered student-active learning through pre/post questions that initiated individual reflection and group discussion, enhanced social learning, and gave teachers information about their own students' thinking
- gathered assessment data efficiently, using the same tool provided to teachers for classroom use, to ascertain what students were learning, and analyzed these data to assess evidence of impact.

In conducting this E/O project, both process and product have proven to matter. We involved teachers in creating, disseminating and learning from the product. Our combined experience has shown that the most- and best-used materials are those teachers have experienced, participated in and created themselves. Some E/O projects have created websites full of curriculum on the content of a research project—but these are necessarily directed to a narrow group of teachers who teach that content in their classrooms, and may offer more information than even those teachers can cover in a standards-based curriculum. Here, teachers gain opportunities to learn and share with their students how science is done and who scientists are—something many teachers cannot otherwise provide to their students. E/O efforts like this one thus give scientists the opportunity to make a meaningful difference in K-12 education.

We are often asked for other films that show research projects in action—perhaps an example that shows more applied research, such as development of new drugs, to compare with the basic science focus of this study. And indeed, it is easy to imagine the greater power of a set of films that enable students to compare and contrast portrayals of scientific research in action. We thus encourage other science E/O efforts to use educational documentary as a tool when the scale of a project permits. Film is an efficient way for scientists to communicate with the public. *Upward and Outward: Scientific Inquiry on the Tibetan Plateau* reaches many more students and teachers than could be reached if the researchers invested the same amount of time in classroom visits. Those who do participate in classroom outreach are using it as a tool for their individual E/O activities. More broadly, we urge E/O projects to focus their efforts on building understanding of the intellectual and social processes of science, which, we argue, can have much greater influenc on public views of science than does understanding of any particular scientific topic.

Finally, we note that this study demonstrates, in a small way, that the education and outreach efforts of scientific organizations can and should take the same evidence-based approach used by the scientists whom they support. There are many reasons this is hard, but we owe it to our audiences and funders to both draw on and contribute to the evidence base about "what works" in E/O. We also owe it to ourselves to demonstrate that science E/O specialists occupy a real profession whose work is deserving of both respect and critical scrutiny.

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