Defining Science In the Classroom:
How Scientists' Views Shape Classroom Practice

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RUNNING HEAD: Defining Science

ABSTRACT

In realizing that science education reform must act across all levels of education, this study looks at the planning and instruction of a reform based, NSF funded, college level science course. This course was team taught my members of different science disciplines and was intended to show the integrated nature of science. Through an analysis of instructor interviews, planning sessions, classroom sessions, and student exit interviews, our research reveals that even such a well intentioned and well supported course can fall short of its intent to portray the nature of science. This is due in large part to individual instructors' goals for science education and views of the nature of science. This has implications for how instructors' definitions of science affect science teaching and science learning.

Defining Science In the Classroom: How Scientists' Views Shape Classroom Practice

While the current reform movements in science education often provide only a vague description of actual classroom practices (American Association for the Advancement of Science [AAAS], 1990, 1993; National Research Council [NRC], 1996), on the following points, each is clear: science teachers should decrease the time spent in the didactic presentation of facts isolated within disciplinary boundaries and increase the use of inquiry-based instructional strategies to help students learn integrated science content that is generated through problem solving contexts.

At the heart of these reforms are two key components. First, for science teaching to change, it must change at all levels of instruction. While we often think of how the reforms should impact elementary and secondary classrooms, the reforms also suggest that if substantative change is to occur, changes must also be made in the way undergraduate science is taught. At the college level, content instruction is often conceptually fragmented and can act as an impediment to learning and teaching reform-based science (Cheney, 1990; Gess-Newsome & Lederman, 1993; Meier, Cobbs, & Nicol, 1998). Without changes in college science instruction, there is little hope that the preservice teachers will learn and be able to teach science differently. The importance of targeting college science instruction has been recognized by funding agencies such as the National Science Foundation (NSF), as evidenced by the increased number of grant collaboratives designed to include members of the science community in reform efforts. Little information exists, however, on how scientists interpret and respond to such efforts.

Second, the goals of science teaching as described by reform efforts are to be framed within more complex definitions of science. New definitions of science and science literacy have been variously described, and each categorization scheme carries with it different commitments for the components of science that should be mastered by students (Eisenhart, Finkel, & Marion, 1996; Li, Oliver, Jackson, & Tippins, 1999). For the purpose of this study, we will draw upon the work of Lederman (1998) who groups the definitions of science under three primary categories: science products, science processes, and science as a way of knowing. *Science products* include the science concepts, facts, and theories that constitute the knowledge base of science. Past instructional practices have emphasized this component of science to the exclusion of all others. Within the new definitions of science, the products of science continue to be important, but within a different context. Instead of memorizing facts and studying disciplines for their own sake, science concepts are recognized as integrated and connected, with knowledge in one field impacting and informing efforts in another. Scientific knowledge is important to the learner not merely as recognized academic cannon, but as personally relevant and useful in problem solving contexts. An understanding of science provides the individual with another way of valuing, appreciating, and interacting with the physical world. *Science processes* provide the mechanism for generating scientific knowledge. While individual skills, such as observation and measurement, are worthy of isolated mastery, their value is found in their creative application in solving problem situations through science inquiry, where physical phenomena are explored and evidence is used to generate and test an explanation. Science processes, then, represent both a goal of science learning (a set of skills and the ability to “do” science) and a pedagogical approach by which to achieve those goals (Adams & Chiappetta, 1999; Lederman, 1998). Finally, *science as a way of knowing* captures the epistemological assumptions that underlie scientific knowledge and its generation, providing a context for subject matter learning (Lederman, 1998). Science knowledge is based on empirical evidence and is tentative. Science is understood to be conducted in a social context, providing opportunities for personal bias and the public adoption or rejection of ideas. Rules governing the generation of scientific knowledge are then situated both historically and culturally. An understanding of science as a way of knowing helps students appreciate the boundaries of science, distinguishing which questions can and can not be approached within the domain. This tripartite definition of science was important in this study for two reasons. First, it captured for us the intent of the science reforms. Second, it provided a useful framework through which to understand the definitions of science held by the participants in this study.

This reformed vision of science and AAAS’s (1993) call to change the way science is defined and portrayed in college classrooms provided the stimulus for the creation of an integrated science course at Bingham College. This course, entitled *The Natural World: Explorations in science*, was funded by NSF in 1996. Involving four faculty members with expertise in chemistry, physics, biology, and writing, the course is described as follows:

> *The Natural World: Explorations in science*, an introductory, integrated science course [for

> non science majors], is laboratory based and experientially driven. It is designed around four major concepts--matter and energy, change and constancy, diversity and order, and interactions--with the following goals: to provide broad, integrated science knowledge, to foster the development of effective process learning skills in science, and to create a continuing interest in science. [Teaching] methods include extensive writing, guided discovery laboratory experiences, reading in the history of science and popular journals, collaborative teams, library/internet research, quantifying phenomena, computer modeling, problem solving, and critical thinking skills. (Grey, et al., 1996, project summary)

As researchers we recognized *The Natural World* as an opportunity to document the planning and teaching of a science course by scientists who understood the need to portray the definitions of science in their classrooms. In this study we set out to capture scientists' definitions of science and to describe how these definitions influenced their planning and teaching in a reform-based, integrated college science course. In order to further illuminate curricular enactment, student outcomes around the primary course goals are also provided.

Study Purposes and Supporting Literature

In a review of the research concerning students' and teachers' conceptions of the nature of science, Lederman (1992) stated that future research needs to concentrate on the context of instruction as a mediator of student understanding. Specifically, he stated that:

> The importance of teachers' instructional intentions and students' perceptions of classroom tasks have been virtually ignored in research on the nature of science. It is not adequate to simply observe a teacher and draw inferences without also investigating the teachers' intentions and the reasons for instructional decisions. It is not adequate to simply correlate instructional sequences with students' conceptions of science without also investigating the students' perceptions of instructional tasks and activities or their recollection of factors which have influenced their conceptions. (p 352)

Lederman's challenge motivated the complexity and scope of the broad question that drove our research: How and why are scientists' definitions of science portrayed through their teaching in a reform-based college science class and how are these definitions perceived by students? This overarching question was divided into the three sub-questions that focused the study: How do instructors' definitions of science shape the manner in which they teach in a reform-based classroom?, How are the definitions of science as described by reforms translated into college level science instruction? and, How are student definitions of science impacted by efforts at reformed teaching practice?

How do instructors' definitions of science shape their teaching in a reform-based science classroom?

While it intuitively makes sense that instructors' views of their content directly impact the manner in which they teach, this idea is not uniformly supported by the research literature. Course structures and instructional actions are influenced and often mediated by a teacher's past teaching and learning experiences; understandings of content; instructional goals, intentions, and expected outcomes; pedagogical skills; the influence of students; and feelings of personal teaching efficacy (Gess-Newsome & Lederman, 1995). This indirect translation of content understandings is exacerbated when the content in question is the nature of science. Many teachers hold inaccurate or incompatible views of the nature of science as outlined by the science reforms (Abell & Smith, 1994; Lederman, 1992; McComas, Clough, & Almazroa, 1998). Instructional practice is not a direct result of teachers' personal understandings of the nature of science (Lederman, 1995). In fact, even teachers with well-formed views of the nature of science rarely use it as an explicit goal when selecting instructional activities (Abd-El-Khalick, Bell, & Lederman, 1998). Finally, the language and activities that teachers use to present science content has additional and confounding implications for student understandings of science (Lederman, 1992; McComas, et al., 1998). A number of researchers propose that teachers' views of the nature of science are closely tied to more general beliefs about teaching and learning (Abell & Smith, 1994; Aguirre, Haggerty, & Linder, 1990), and that these more generic beliefs also may have a direct impact on instruction (Laplante, 1997; Yerrick, Pedersen & Arnason, 1998). Much of the research into teacher's views of the nature of science had been conducted with elementary and secondary teachers. Little is known about how scientists' conceptions of the nature of science impact their teaching. The study presented here will address this deficiency.

How are the definitions of science described by reforms translated into college level science instruction?

The second goal of this research was to examine how the definitions of science were portrayed through the act of course planning and enactment within the context of reform. Content integration was a prevalent aspect of the definition of science and was central to the writing of the grant proposal and the planning and implementation of the course. The definition of integration used in this study mirrors that of Beane (1995) in that learning is organized around the exploration of concrete problems, and knowledge is sought and applied without regard to disciplinary boundaries for the purpose of generating knowledge and solutions as opposed to passing a test. Numerous reform documents have also advocated the importance of content integration, citing the advantages of more powerful student content understandings organized around central ideas, curricular relevance, and increased motivation and interest. Unfortunately, few studies exist to support the increased value of an integrated curriculum (Czerniak, Weber, Sandmann, & Ahrern, 1999; Huntley, 1999). An examination of the transformation of instructor and course goals through the process of planning and implementation can shed light on the challenges and successes potentially inherent in an integrated curriculum. McComas and Wang note that there are “virtually no blended science classes in post-secondary environments” (1998, p. 345), justifying the examination of this unique course feature.

Research on teaching within a reform context or on attempts to reform practice have elucidated a number of barriers to reform as well as factors that are necessary but not sufficient to facilitate reform. Specific barriers to implementing an integrated curriculum include time to plan and teach; inadequate breadth of content knowledge by the instructional staff; limited experience in the team teaching process; absence of administrative support and funding; and absence of curricular materials and instructional models (Czerniak, et al., 1999; Huntley, 1999; Mason, 1996). In our estimation, NSF funding of the project at Bingham allowed for the removal of many of these barriers. Funding allowed for the inclusion of the efforts of highly committed, knowledgeable, and experienced faculty; time to plan and implement the course as provided by the grant; funding for material resources; design of a new course without external pressures for content coverage; institutional support for team teaching with members of diverse content expertise; assistance in grading and data collection; and small class size. As a result, we considered the reform context at Bingham to represent a best case scenario for reform, thus providing a context that allowed for the careful examination of the process of implementing reform.

How are student definitions of science impacted by efforts at reformed teaching practice?

Previous teaching practice has reinforced the importance and relative ease of teaching factual science content, but less information exists as to the merits of integrated instruction for science learning. In one study, college students in integrated science courses viewed science as more meaningful and relevant (McComas & Wang, 1998) than those students engaged in more traditional science instruction. Will such results hold true in this context? More importantly, will students leave the course with a new understanding of the integrated nature of science? Instruction emphasizing science process skills have been positively correlated with student attitudes toward science and confidence in learning science (Downing & Filer, 1999). Evidence also suggests that involving students in an inquiry-based classroom rarely results in changes in their views of the definitions or nature of science (Lederman, 1992, 1998).Will this course shape students' definitions of science? Will science processes be viewed as a set of skills, a way of generating knowledge, or as a pedagogical technique? Finally, the nature of science was initially viewed as an important goal in this class. Literature in this area suggests that unless there is explicit instruction on the nature of science, few changes in student conceptions can be expected. How successful was this course in conveying to students elements of the nature of science? How are students' definitions of science shaped by the knowledge and beliefs of the course instructors and the manner in which the course was implemented?

Context

The Natural World was offered at Bingham College, a private, independent, four year college, noted for its small class size and low teacher/student ratio. A small college, Bingham enrolled approximately 2,000 undergraduate students, 500 graduate students, and employed 100 full-time teaching faculty. The college offered professional and liberal arts courses of study, majors in 23 disciplines, and select graduate programs.

The 19 students enrolled in *The Natural World* reflected the ethnic, age, and academic diversity of the campus student population. Seventeen of the students were of European ancestry and 2 were African American. There were equal numbers of freshmen and upper level students and of men and women. Eleven of the students were pursuing their college education full time, 8 had full-time employment in addition to their school duties, and 3 were second career students. Two of the students were seeking science majors, with one student pursuing a secondary education certificate. Of the 17 non-science majors, four were majoring in elementary education.

Four faculty at Bingham were involved in the planning and enactment of the course: Albert, Brian, Randall, and Christine. Each member of the team contributed a different type of pedagogical and content expertise. Albert, a physicist/chemist, was the instigator and major motivating force behind the conceptualization of the course and the subsequent grant application. Randall, a biologist, had been engaged in conversations with Albert about such a course for a number of years, leading to Albert's development efforts. Brian, a physicist, was a novice faculty member searching for ways to improve his teaching, and so volunteered to participate in the project. Christine, a writing specialist at Bingham, worked with Albert on grant development and was involved in the planning and implementation of the writing aspects of the course. Although involved in the project, due to her lack of science background and the limited role she played in the science content development in the course, Christine was not a focus of this study.

Two of the authors acted as members of the grant evaluation team. The first author was a participant observer (Ely et al., 1998) and collected data in all class sessions, attended instructors' debriefing sessions, and completed the student exit interviews. The second author was involved in the early stages of grant planning and interviewed the course instructors. The third author was involved in data management and organization. All three authors were involved in the data analysis.

Methods

The conceptualization of this research began with the initial drafting of the grant proposal, as evaluation procedures were prominently featured in the grant. Thus, data collection began with recording the initial grant planning meetings and continued through all aspects of course planning, implementation, and debriefing.

The research was conducted in accordance with *case study* methodologies (Miles & Huberman, 1994). As such, the research was structured around more fully codified research questions answered using somewhat standardized data collected procedures. This study required us to focus on the definition of science used by course instructors, the manner in which these definitions played out in course planning and enactment, and the impact of this enactment on students' conceptions. In order to more faithfully attend to each of these foci, both direct and indirect measures of data collection were employed. As described by McDiarmid (1992), it is important to triangulate findings from direct and indirect measures in order to increase the faithfulness of the descriptions generated. The use of direct measures alone can be misleading, as they can often trigger socially acceptable responses and fail to elicit participants' true conceptions. The sources of data for this study included:

Course planning sessions (recorded and transcribed). Seventeen, 1 to 2 hour sessions were held in the summer before instruction, and 10 sessions for both planning and course debriefing were held during the semester of instruction.

Instructor interviews (recorded and transcribed). (See Appendix A for the interview protocol.) Each interview lasted approximately 2 hours.

Class sessions (including participant observer field notes, field journals, and transcripts from recordings of select days of instruction). The class met for 2 hours, twice each week for the 15 week semester.

Student exit interviews (recorded and transcribed). (See Appendix B for the interview protocol.) The 30-50 minute exit interviews were held with each student after the end of the course.

Classroom artifacts such as syllabi, handouts, and student work.

Instructor Case Studies

Instructor interviews and course planning sessions were used to describe instructors' definitions of science. At the outset of analysis, a general analytical framework was used, that of science as products, process, and way of knowing. The interview transcripts were used as a more direct measure of the manner in which the instructors defined science. Instructors' comments in the planning sessions were used as indirect measures of this definition--allowing us to describe the manner in which the instructors' stated definitions were reflected, omitted, or contradicted in the less-structured course planning sessions.

Three stages of data coding were employed in the analysis of the instructor case studies: open, axial, and selective coding (Creswell, 1998; Strauss & Corbin, 1998). Given this general framework, the transcripts from the instructor interviews and planning sessions were coded by two authors in a process of *open* coding to further identify the emerging themes. The use of multiple coders was employed to allow for peer checking of themes. Themes emerging from each data set were compared to identify potential themes for each participant. As an example of such comparisons, Randall's rejection of anthropocentrism was identified in the separate analysis of both his interview and the planning sessions.

After tentative themes were identified, both data sets were analyzed again to look for negative instances of potential themes (Ely, et al., 1998; Miles & Huberman, 1994). Themes were then revised based on their ability to account for or explain the negative instances; those that could not explain the negative instances were abandoned. Data clips that addressed these themes were grouped together and themes were arranged into broader categories in a process of *axial* coding. To extend the data analysis example, Randall's rejection of anthropocentrism was subsumed under his conception of the ecological relevance of scientific knowledge. This theme of ecological relevance--with the underlying rejection of anthropomorphism--was then placed under the product category of his definition of science.

For the final stage of data analysis, known as *selective* coding, concept maps were constructed to organize the broad categories and their constituents and to make explicit their interconnections. Returning to our example, Randall's conception of ecological relevance was linked to his emphasis on the complexity of scientific knowledge and well as his need to take control of teaching through telling a story. Narratives that describe each instructor's view of the definition of science were written based on the concept maps and reviewed by the entire writing team.

Course Planning

Three instructional episodes were purposefully selected for case study analysis (Creswell, 1998; Patton, 1989). Specifically, we selected episodes that were planned primarily by one instructor to provide the best opportunity to describe how individual instructor's definitions of science impacted course planning and/or curricular enactment. It is important to note, here, that an early unit on the nature of science was deliberately not selected for analysis. In our sample, we wanted to document how the definitions of science were woven through typical course instruction, and it was our judgement that the unit with the sole focus on the nature of science would not be representative of typical class instruction. The teaching episodes selected included science journals (highlighting Albert), population growth (highlighting Randall), and light (highlighting Brian).

Transcripts of all of the planning sessions were reviewed by two authors to search for any instances in which the specific teaching episodes were discussed. These data clips were reread for meaning, and a set of questions (Appendix C) were used to interrogate the data for each episode. The answers to the questions were used to write the narrative of the planning of each instructional episode.

Curricular Enactment

A similar process as described above was employed for the analysis of curricular enactment. In addition to classroom transcripts and field notes from appropriate class sessions, class artifacts, such as the syllabus, related handouts, and homework assignments, were also reviewed. The questions that were used to interrogate the data to construct a narrative description can be found in Appendix D.

Making Sense of Teaching Episodes

The analysis of the planning and enactment of each instructional episode occurred after the instructors' cases were written. The findings of the cases allowed us to compare and contrast instructor goals and definitions of science against their participation in curricular planning and enactment. Thus, the analysis of each episode represents a synthesis of each of the three data sets, describing the interactions of individual definitions of science with that of the class goals designed by the group, and illustrating the manner in which these interactions impacted curricular enactment.

Student Conceptions of NOS

Transcripts of the exit interviews were used to analyze students' definitions of science using the open, axial, and selective coding techniques described previously (Creswell, 1998). The interview transcripts were used as an indirect measure of the manner in which the students defined science. In particular, statements concerning student perceptions of the content or pedagogy of the class were analyzed in terms of the themes related to the three aspects of the definition of science (process, product, and way of knowing).

Results and Analysis

This study examined the definitions of science used by three scientists and the factors that impacted the way in which these definitions influenced their teaching in a reform based, integrated science course. As such, this section will include 1) case studies that detail the three scientists' definitions of science, 2) descriptions of the planning and enactment of the three teaching episodes, and 3) an analysis of these data sets.

Instructor Case Studies

Albert: Careful experimentation with his teaching

There were some remarkable parallels between Albert's personal appearance and his professional demeanor. His appearance gave the impression of boundless energy, directed elsewhere--his dark bushy hair and beard were so long they threatened to overtake his face, his clothes were invariably casual, suggesting that they were hurriedly thrown on while Albert's thoughts were elsewhere. This sense of energy was also present in his interactions. Albert was curious about almost any topic that surfaced in conversation, whether it was science, music, art, teaching, or literature—and he peppered conversations with endless questions. Because he tended to use his broad knowledge base to understand any particular topic, conversations with Albert promised to lead almost anywhere.

Surrounded by electronics equipment, geology samples, and artifacts of summer excursions to archeological digs, Albert's early love of science developed through his interactions with his father and culminated in undergraduate college majors in chemistry, physics, and mathematics, a Master's in particle physics, and a Ph.D. in analytical chemistry. Extensive teaching opportunities as a graduate student lead to the acceptance of a last-minute high school science teaching position, and eventually his job at Bingham.

Albert claimed that his high school teaching experience was the "key to everything that I've done [at Bingham]" (I-18), allowing him to see the value of "exploring" through his teaching (I-16). Experiments in instructional design gave him "accumulated insight into how it is that these people are learning" (I-23) and acted as the data in his constant attempts at improving his teaching practice. His teaching experiments cemented a science teaching philosophy that revolved around students. Specifically, Albert believed that: a) concrete experiences were prerequisite to student construction of more sophisticated understandings, b) student interaction was critical to learning, c) learning occurred through structured problem-solving opportunities, and d) student questions should shape instruction. It is this student-centered framework for teaching that led Albert to initiate the grant proposal to create *The Natural World* while in his seventh year teaching at Bingham.

Albert viewed science as "problem solving from four different angles" (I-13). This explanation hints at important components of Albert's definitions of science. Foremost among these is that *scientific knowledge* *is integrated*. Albert's values and definitions of science are summarized best in his description of the important aspects of *The Natural World*:

> [The course is] interdisciplinary because I think that's the way life is going in the sciences...[The students are] going to have to deal with trying to understand the world out there. Well, the world out there doesn't respect the boundaries that we've constructed....That's where science is headed now, multi-disciplinary teams attacking big problems. (I-26).

Inherent in the above quote is Albert's identification of the role of science as *the application of scientific knowledge and processes in problem solving*. Selecting science knowledge for classroom instruction was then based upon understanding the problems students will encounter, with problem solving skill taking priority over a detailed understanding of the physical world (or the products of science). Albert believed that students must acquire process skills in order to "truly understand science" (P-6/27, 3), and that process skills needed to be taught in tandem with content, because "if all you do is focus on content, then you will never pick up the experimental skills--it will not happen" (P-6/25, 4). For Albert, use of these processes then become "the reason to want to know" the content of science (P-7/9, 12).

Albert placed more importance on the role of process skills and problem solving in science than the other course instructors, and had a more sophisticated view of the manner in which problem solving impacted the production of scientific knowledge. On several occasions during the planning sessions Albert argued strongly with Randall that there was *not <u>one</u> scientific method* and he forcefully rejected the sole hypothetico-deductive model championed by the state board of education. Likewise, Albert understood the *historical and cultural impacts on scientific knowledge construction* to be an important aspect of the nature of science and used this rationale for designing a unit illustrating how science is a product of the culture in which it is conducted. Albert also understood the *tentative nature of science* to be important, and argued with Randall for the inclusion of immunological theories because they were still under revision within the scientific community:

> I think that it is a valuable thing for them [students] to come away with...we thought we understood a lot but now we're finding out that we didn't understand it so well...there's an awful lot here that we don't understand yet--the tentative nature of science, the growth [of science knowledge]. (P-6/25, 12-13)

Randall: Comfortable with teaching as crafting a good story

In many ways, Randall was the quintessential biology professor. Sporting a salt-and-pepper beard complemented by thick gray hair, he invariably chose khakis and short sleeve shirts for professional activities. His office and vehicle were a jumble of field guides, plant presses, and collection jars. It was often difficult to find Randall due to his busy schedule and laxidasical approach to appointments. During the interview, as in the classroom, Randall spoke in a slow, melodious cadence, often pausing to rub his beard in thought. His smile was warm, given frequently, and once engaged in a conversation or lecture, Randall gave the impression that he relished the interchange.

Randall's love of nature was formalized in college with B.S. in biology and a M.S. and Ph.D. focusing on physiological ecology topics. In his early faculty positions he experienced difficult conflicts between maintaining a research agenda and the unfamiliar demands of teaching, resulting in a move to Bingham. At the time of the study, Randall had been teaching at Bingham for 10 years.

Randall noted that he "was thrown into my first university position... with absolutely no educational background or experience" (I-5). Early teaching attempts were "traditional" and unsatisfactory ("I wasn't a good teacher") until Randall discovered his knack for weaving science content together into a compelling story line while teaching in the out-of-doors. The result of these early teaching experiences allowed Randall to understand that the most effective way of teaching was a good story. This conception helps explain Randall's view that science teaching reform should revolve around a change in content orientation (i.e. focusing on conservation issues) rather than a change in teaching practice. Despite the explicit inquiry focus of the course, Randall remained skeptical: "I'm still not convinced that the most efficient way it to teach [the concept] isn't as a story rather than the [inquiry] we've been trying to do in this course" (P-6/26, 2).

Just as Randall's views of teaching were shaped by experience, his conceptions of science were forcefully shaped by his ecological commitments. For Randall, science had *profound ecological relevance*, lending greater importance to issues related to the "health of our environment rather than the technology of human health" (P 7/2, 4). In contrast, religion provided a human-centered vision of the earth and *science was a rival of a religious, anthropocentric orientation*. Thus, a primary goal of science teaching was to supplant students' religious, anthropocentric views with his scientific, ecological perspectives: "[A science course should] address the powerful anthropocentrism that all students come to us brainwashed with" (P-6/7, 2).

Randall's fondness for creating science stories was related to the importance he placed on teaching scientific knowledge, as demonstrated by the following excerpt:

> We [the planning group] wanted investigative, hands-on kinds of learning, but the two [topics] that I've just mentioned [geological and biological history] can be told by story--not by scientific logic and deduction....*To do it by story is to say that all of this story has been deduced from the scientific method*.... we just don't have the time to give you [the student] the appreciation of all these phenomena that have been learned in the history of science.

Clearly, Randall found the products of science to be more important than the processes of science, and throughout the planning sessions Randall was often a vocal opponent to Albert's inquiry-oriented approach, "We don't have time with this hands-on approach to convey that [concept]" (P-6/27, 4). Instead, Randall saw the products of science, its theories and concepts, as too complex and too important to be conveyed in any manner other than a well-crafted story.

Part of Randall's commitment to teaching from a story line may have been based on his appreciation of the integrated nature of scientific knowledge. It was obvious from the planning sessions that Randall believed that any one concept could be approached from a variety of disciplines, and he valued this integration from both content knowledge and pedagogical perspectives. For instance, in the planning of the structure and function unit, he suggested the examination of the structure of a variety of macroscopic and microscopic materials (i.e., mountains, rocks, wood, bones, and cells) with the student focus of "why do they look like they do?" (P-7/2, 6). For Randall, such instruction would foster an integrated approach to science.

Randall's framework for science, *while sophisticated in some areas, was by no means uniform*. For instance, Randall understood the products of *science to be tentative, changeable, human constructions dependent on underlying culture*. In the planning sessions, however, he argued against teaching more tentative scientific concepts (such as the immune system) because of their uncertainty. Likewise, on several occasions Randall spoke of *teaching "the scientific method" as if there were one approved method.* In later stages of course planning, there was evidence that he had become disenchanted with this singular conception, potentially stemming from the difficulty he had in describing the actions of a naturalist in terms of a strict, hypothetico-deductive method. Clearly there were incongruities in Randall's conceptual framework for science.

Brian: Learning to Reform his Teaching

When looking for Brian between class sessions, students would first check for his bike and helmet stashed in the back of the laboratory/classroom. The search was generally short as Brian put in long hours, earnest about being available to students. Brian's careful appearance was contrasted by his animated movements and quick humor when in front of the classroom as he often cast himself as the brunt of classroom jokes. As an instructor, he deliberately listened to students' comments and questions, working to mesh their contributions into the lesson. Outside of the classroom, Brian was often quiet, seldom speaking in the course planning sessions unless it was clear that his contribution was required. In these sessions he assumed the role of a learner.

Brian viewed science as a lens that could be used to "see the world in an entirely different way" (I-3). He was first drawn to physics as a way of understanding the hobbies that he loved: music, photography, and swimming. An undergraduate degree and work in aerospace engineering led to a Ph.D. in physics with research in fluid dynamics. Brian's first faculty position was teaching physics at Bingham. At the time of the study, Brian had been teaching for two years.

Similar to the other instructors, Brian had little formal preparation in teaching but was conscious of the teaching practices he experienced:

> [Even in grade school] I remember looking at teachers and going "I'm not going to do it that way. I don't like the way we're doing this. This doesn't work for me." And so, I've always thought I was going to be a teacher. (I-2)

Brian's teaching commitments were sparked by his own difficulties learning physics and fueled by watching his students experience the same challenges: "it's just so hard to see [the struggle] on their faces" (I-6). At the time of the study, Brian recognized traditional didactic teaching approaches to be largely ineffective and he hoped that his participation in *The Natural World* would help him learn how to reform his teaching.

In order for science learning to be meaningful, Brian believed that students needed to take ownership of their learning, actively grappling with phenomena as they searched for answers. This conviction required him to allow students to struggle with ideas, an approach he found difficult to maintain:

> I am still kind of like a mother, wandering around going, “Here, let me adjust this for you.” [The students] need guidance, but it’s hard not to just do it for them and just tell them what’s going on instead of trying to draw it out of them so that they will have the ownership of it (I-6).

While inquiry was a new teaching approach for Brian, he eventually became its champion in Albert’s absence during the planning sessions. On several occasions, he argued with Randall about the appropriateness of inquiry teaching, “We’ve got to get away from telling them [the students] these things [concepts]!” (P-6/7, 4).

When asked directly in the interview, Brian offered a fairly traditional description of *science as “predictive, testable, and interconnected with the other sciences*” (I-11). An analysis of the planning sessions, however, revealed the sophisticated nature of Brian’s definitions of science. While Brian understood science to be a powerful means of understanding the natural world, he acknowledged that processes of science imbued it with boundaries, “*Science does not have all the answers*, it is not the end all” (P-6/7, 5). Brian wanted his students to leave the class with an understanding of “what is and what isn’t science” (P-6/7, 6). He was much more aware of these boundaries than Randall, as evidenced by an exchange on the distinction of “how” and “why” questions. In this exchange, Brian explained that science could only address “how” a phenomenon occurred--a distinction that remained unclear to Randall (P-7/23, 5).

Brian described the processes of science as an important aspect of the course, emphasizing “how we know what we know” for each of the topics taught (P-6/7, 10). In addition, he believed that *students should learn to <u>do</u> science*. For instance, early in the planning sessions, Brian wanted students to keep science journals--because that is what scientists do. He wanted students to make observations and collect data so that they could see the sometimes inexact nature of scientific measurement. He thought students should draw conclusions based on data so they could recognize how personal bias (and therefore culture) influenced the construction of science knowledge.

Brian’s understanding of the products of science is closely related to his conceptions of scientific processes. He understood *scientific knowledge to be tentative*, and he worked to convince Randall of the inaccuracy of the notion that scientific theories ultimately become laws (as portrayed in the course text). He saw *scientific knowledge as integrated*, although he was less articulate on this point than either Randall or Albert--perhaps reflective of the degree to which Brian had to become familiar with other scientific disciplines (such as biology and geology) in order to teach this course. Thus, like Albert, he viewed science as relevant and integrated, as reflected in his goals for the students in his class:

> Hopefully [after the class] they're going to make the proper decisions that are going to affect themselves and the rest of the world...they are going to be better citizens. [And] I hope [their knowledge of science] enriches their aesthetics. Just like a sunset is enriched to me; sunsets are absolutely gorgeous in their own right, but knowing even more about them makes them even more gorgeous. (I-8)

The Scientists' Definitions of Science and Comparison to Course Goals

As portrayed in the cases, each of the three scientists had complex, but different, definitions of science. Albert, who was the most articulate in his discussions of science, felt a strong need to portray the utility of science processes to his students. Brian was much like Albert in his emphasis on the processes of science, although Albert's problem solving emphasis was replaced in Brian by a strong commitment to the personal relevance of science. Randall was a notable exception to this emphasis on process. For Randall, the products of science had primary importance. Randall felt it was essential for students to throughly grasp the ecological importance of science, and so it was imperative these complex products were understood by the students. Thus, for Randall, the products of science were far too important and far too complex to be conveyed in a process-based approach to teaching.

As shown in Figure 1, not only were the definitions of science employed by each of the three instructors different, each had a varying degree of fit with the course goals. Of the three, Albert's definition of science most closely matched the course goals. Brian's definition, though not contradictory , fell short of the definitions inherent in the course. Randall, in contrast, had fewer aspects of his definition in concert with those of the course or the other instructors.

Insert figure 1 about here.

Course Planning and Enactment

The course planning sessions provided an opportunity to see how the instructors' definitions of science interacted with each other and the eventual curricular plan. The instructors met on 17 occasions, for 1 to 2 hours, during the summer prior to the initial offering of the course. Early planning sessions were characterized by lively conversations between Albert and Randall, with Albert's emphasis on the broader course goals colliding with Randall's need to detail actual class activities. Brian, frequently quiet in these early sessions, became more vocal in later sessions, demonstrating his careful attention to the language of the reform modeled by Albert. The dynamic of the later planning sessions changed as Randall and Brian worked on their own. In these sessions, Brian took on Albert's role and engaged in earnest, but muted, arguments with Randall. The conversations revolved around the teaching methods and activities to be employed with Brian championing reform based teaching methods.

The analysis of the curricular enactment provided an opportunity to examine how course goals and activities, often designed by the group, were transformed into instructional practice by individuals--another lens for the examination of the impact of individual and group conceptions of science on instruction. The following section will describe the planning and enactment of three specific instructional episodes: science journals, exponential functions/population growth, and light/spectroscopy.

Course Overview

While our analysis focused on three instructional episodes, a broad description of the course is offered to provide a context for the episodes. The major instructional topics during the one semester course included: nature of science, including process skills such as writing, observations, classification, and the cultural embeddedness of scientific ideas (6 sessions), rock cycles (5 sessions), exponential functions and population growth (1 session), lunar cycles (1 session), light/spectroscopy (2 sessions), and structure and functions of biotic and abiotic systems and sub-systems (7 sessions). The remaining 7 sessions were spent in examinations, discussion of course logistics (i.e., syllabus, assignments), semester project work, and class presentations.

The three instructors were involved throughout the class, but to varying degrees. Albert was primarily responsible for instruction during 13% of the class time, Randall 44%, and Brian 36%. The remaining 7% of class time was the responsibility of the writing specialist, Christine. While these figures represent primarily instructional responsibility, both Brian and Randall were present during most of the class sessions and assisted in a supporting role when not the instructional leader. Albert and Christine were present throughout the course, but to a slightly lesser degree.

In order to represent the manner in which class time was spent, instructional activities across 8 randomly-selected class sessions were tallied. As shown in Table 1, the most common instructional activities included lectures, triadic dialogues (as described by Lemke, 1990), and small-group, hands-on activities. To a lesser degree, small group discussions were also a common feature of the course.

Insert Table One Here

Science Journals

Journal Planning. The journal writing episode was selected because of the central role Albert played in its conception. Although others (primarily Brian and Christine, the college writing specialist) shared the teaching of this major course component, from the earliest planning, Albert took responsibility for the planning and design of the science journal assignment. While writing was understood to be central to the course from the outset, the instructors' understandings of the role of writing evolved throughout the planning and provided insight into how scientists' work was viewed, as well as the integration of science content and processes in generating and understanding scientific knowledge.

In the grant proposal, Albert and Christine described journal writing as a tool to help students to: "write clear explanations using appropriate sketches, pictures, etc.; to describe observations, concepts, models, diagrams, predictions, and speculations; use writing to explore science; and to record the evolution of scientific thinking and process" (NSF proposal, 4). In the early planning sessions, the group's conversations revolved around journals as a place for students to document their research activities, a "notebook of information" for future reference (Randall, P-6/18, 7). But, as Randall outlined his approach to journals, Albert disagreed, describing the journals as a vehicle for documentation and a place for students to hone their skills of observation and description. Christine continued the development of this conception, noting that "students need[ed] to learn to ask questions... [the journal will require] the kind of descriptive writing [that uses] all the senses" (P-7/16, 17). Christine stressed that through the "reflective writing" aspect of the journals, students could grapple with the science content of the course. This idea stimulated Albert to see the course as revolving around students reflections and making sense of the course activities through their own writing, with an individual class session structure of "experience and write, experience and write, experience and write" (P-7/16, 17). Adopting this goal, Brian insisted that "we have time at the end [of class] for their reflective writing" (P-9/20, 20) and that the reflective writings could also serve to integrate the course concepts. Albert, recognizing the utility of this approach, suggested that the reflective writings were an ideal place to ask students to apply and integrate the different materials they were reading in and out of formal course assignments and make sense of the broader aspects of science.

The final roles to be fulfilled by the journals included a means to record research efforts, writing to learn, as well as an avenue for assuring integration of concepts, as reflected in its description in the syllabus:

> Creating an outstanding science notebook filled with careful observations, and data collection, drawings and simple calculations, and thorough summary/reflection sections complete with documented references to the text, outside sources, and extra science reading and viewing. (Syllabus, 5)

Journal Enactment. The journals played a major role in course instruction, accounting for 40% of the course grade--an amount four times greater than any other course assignment. Albert, in his introduction to the course, stated: “Your science notebook is going to be your lifeline in this class” (C-8/29, 7). Similar goals and explanations were offered by the various instructors:

> Brian: Writing is very important in this course....This is going to be writing to figure out what you know and what you don’t know. To record what you’ve been doing...and understand what is going on. And it’s going to be a record of your scientific evolution in progress. How have you changed as you’ve been going along this semester? (C 8/29, 4)
>
> Albert: We want you to learn how to use writing as a learning tool. To use writing as a scientist does. To get down your current thoughts and ideas of where they’re at and use it to help crystallize those thoughts and guide them in a new direction. Writing to learn....That’s going to be a useful skill. (C-8/29, 14)
>
> Christine: Your science notebook is...your own attempt to create a textbook and record the progress of your own scientific knowledge. (C-8/29, 18)

In these comments, we see the journals described as a means (a) to collect and record information, i.e., “create a textbook,” (b) to record course activities, (c) to refine the science process skill of writing, (d) to learn to use writing as a means of refining science content knowledge, i.e. “writing to learn,” and (e) of metacognitive awareness of student learning.

Instruction on journal writing occupied a significant portion of the early weeks of the course, as the instructors described and modeled the kinds of observations, reflections, questions, and integration that they sought. Of the 29 class sessions, science journals were the explicit focus of instruction for some portion of 8 of the class sessions. During 12 other sessions, 5 to 20 minutes of class time were set aside for reflective journal writing. While not explicitly focused on during 7 of the 9 remaining class sessions, journals were mentioned during some aspect of each of the instructional activities (i.e., Randall's "be sure to get this in your journals.")

Explicit journal instruction occurred during the first three class sessions and was lead by Christine and Brian with tangential involvement by Randall and Albert. Class activities provided students with the opportunity to develop and refine their observational and writings skills as opposed to a focus on content. For instance, Randall led the students on a walk to a nearby stream as a means of making observations. Back in the classroom, Christine was responsible for allowing students to write, debriefing on the observations, and helping students understand how the observations should be recorded in their science notebooks. To accomplish this, she relied on student centered discussions and the modeling of her own journaling attempts.

Subsequent class sessions changed the focus from using the journals as a means of recording observations, to emphasizing the reflective aspect of the journal assignment, in which students were to "get at what you know, to refine your knowledge" (Brian, C-9/3, 11). To achieve this goal, the students were to record in-depth observations of both a leaf and a rock, reflect on what they knew about the objects, "make connections between ideas and concepts," and "record their feelings, their interests" about the subject (FN-9/3). Christine described these writings as "participating in the ongoing conversation of science." Much of the early instruction in reflective writing was deductive in nature, with Christine and Brian establishing the intent behind the assignments and describing the manner in which students were to achieve these objectives. Again, the emphasis was on refining the process skills of observation and writing, not on the content of these observations.

The class activities in the second session continued to emphasize the dual nature of the journals--that of recording observations and reflecting on what was being learned. Again, using an activity in which students were to investigate a question, in this case “Why is it hard to turn the generator?,” students were to record observations and make reflections on their knowledge, thus refining their observational skills as well as their writing abilities. As before, the emphasis was on process skills as well as a discussion of the nature of scientific explanations (including a comparison of the meaning of terms such as *hypotheses, theories, and laws*)--but the emphasis was not on the science content of electricity or generators.

In the third class session, and echoed throughout the course, it was Brian who continually pushed the various instructors to set aside time and attention for journal writing at the end of each class session. On several occasions, Brian eliminated course activities in order to allow time for reflective writing. In contrast, Randall seldom devoted class time to this activity. Recognizing the emphasis Brian placed on writing, he became the instructor that students came to with journal questions:

> Student: What are these reflective thing-ies [journal reflections] supposed to look like?
>
> Brian: Reflections are something you need to do at the end of class...when things are still floating around....[Summarize] what you did that day...What are some of your personal reflections? What did you get out of that class?...How does it affect you? How do you affect it?...Bring stuff [outside readings] in and make connections from other places also. [In the journal reflection] you can tie it all together and then start mulling about how it affects you and how it affects other things around you. (9/10, 1-2)

As is demonstrated in this passage, while each of the instructors supported the achievement of integration through outside readings and experiences, it was Brian who gave the voice to this approach. It was Brian that emphasized that students were to bring together ideas from a variety of sources in the reflective writing for their journals.

In contrast to the explicit focus on the journals early in the course, in subsequent class sessions students’ journals became a tool to record and make sense of the content presented in the course. Important features of the journal assignment were reinforced in the grading rubric that was designed to assess each of the stated instructional objectives: writing as a process skill, writing to learn, writing to record and maintain information and activities, writing to integrate knowledge, and writing as a metacognitive activity.

Making Sense of Journal Planning and Enactment. In the journal activity we see a clear translation of the instructors' definitions of science into course enactment. Albert and Brian's emphasis on science processes were reflected by the manner in which the journal was used as a tool for conducting science, requiring students to refine skills in observation, data collection, and in asking questions of their data. The skill emphasis was a clear focus of much of the explicit journal instruction seen early in the course. But more importantly for these instructors was the role journals played in knowledge construction. That is, both Albert and Brian understood that the process of reflection would facilitate student understanding of the science, an emphasis explicitly addressed on many occasions in the class.

The journals also reflected the instructors' conceptions of the products of science. While journaling was understood to be an important process, the concepts the students were developing were also valued by the course instructors. The integrated nature of scientific knowledge was emphasized by the requirement that students integrate information from many areas and diverse domains, an aspect that was clearly valued by Albert and Brian. It is interesting that while Randall recognized the integrated nature of scientific knowledge, he was much less vocal on this aspect of the journal assignment than the other two instructors. Instead, for Randall, the journals were to serve as a place to collect the knowledge addressed in the course. Again, we see Randall's clear emphasis of the products of scientific knowledge over the processes of science.

Finally, the journal assignment enactment also allowed for an analysis of instructor views of scientific relevance. Brian and Albert emphasized journal writing as a tool to examine how the knowledge generated in class was relevant to student lives. For Brian, the journals allowed for a form of enculturation, a mechanism for students to "act like scientists," a role potentially explained by Brian's own tendencies to journal his scientific work. In contrast, Randall's emphasis on ecological relevance was not addressed in this assignment. Whether because of this omission or as a result of it, Randall ignored the role of journaling in the class, relegating the journal as an endpoint for the knowledge he presented.

Why did the planning and enactment of this activity allow for such a clear translation of teachers' conceptions of science? Why was this activity such a clear embodiment of the course goals? The journal assignment represents a merger of the conceptions of each of the course instructors. Emphasized early in course planning, the journal assignment consumed a large portion of the group discussions, allowing for the incorporation of critical ideas from each of the participants. The journal assignment was an assimilative activity that housed much of the instructors' definitions of science and served as a vehicle through which their students were to construct similar conceptions. Additionally, the grading of the journals acted as an anchor to tie instructors' teaching to their original planning and served as a clear mechanism through which students could gain insight into the instructor's expectations. Developed by the group, the comprehensive grading rubric closely reflected the diverse conceptions of science held by these three scientists.

Population Growth

Population Growth Planning. The population growth episode was selected due to the major role Randall played in its planning and enactment. Early course planning revolved around group discussions of major themes that would integrate key concepts and processes. The theme of exponential function was introduced into course planning through multiple avenues. The first time occurred when the group was considering ecosystems as an organizing theme. During the conversation, Albert tried to convey to Randall how an ecosystems theme united multiple concepts, specifically equilibrium and systems, under one general, concrete category: "let's look at mankind as part of the ecosystem....okay, back at equilibrium you'd have to look at an ecosystem and see what's going on. So obviously you're going to pull systems back in for several ideas" (P-6/25, 13). Yet, Randall insisted on using population growth as a central concept for similar reasons:

> Randall: No, I would use population growth rate with human organisms.
>
> Albert: That's pretty specific. That would be part of it.
>
> Randall: You can show human populations and equilibrium for thousands and thousands of years and something happened to change the number of births over deaths.
>
> Albert: I see what you're saying. That should be in here under equilibrium. Sure.
>
> Randall: Well, population growth models. (P-6/25, 13)

Randall was especially interested in showing how humans interact with the environment as human population growth exponentially increases, again reflecting his emphasis on the ecological relevance of scientific knowledge. At this point in the planning, there was no explicit decision made regarding which conceptual theme would be used or how the theme would be addressed. So, while no team member denied the importance of the concepts of population growth and exponential function, the motivation behind their inclusion varied across the instructors.

As general course planning continued, the theme of graphing and mathematical relations emerged as a concept used throughout the sciences and which is seldom understood completely. At this point, exponential functions were brought up again, and Randall again suggested population growth as a concept, tying it to other exponential relations such as radioactive decay, cell division, etc. The team approved of the idea, but the grander theme of mathematical relationships was quickly lost to the important, yet less encompassing, concept of population growth.

In planning this part of the curriculum, an activity was proposed to give students a firsthand understanding of exponential growth. Brian suggested: “If you do [an activity] with pennies 1, 2, 4, 8, 16, 32, they could see the explosion.” Randall, in response, quickly segued into his vision of the unit: “So that could start the discussion on human population growth” (P 6/27, 6). This excerpt exemplifies Randall’s secondary view of the exponential function aspect of the lesson, a view that continued through the planning of this instructional episode. When it was later discovered that only Randall and Christine would be in class on the day of this lesson, the group left the final planning to Randall. Once Randall was given/accepted the final responsibility for teaching the topic, Randall told the group that he would use the penny stacking activity because it “would be fun” (P-7/17, 4). He then arranged to have this activity assigned as homework the day prior to the class presentation so the class time could be used for a lecture and a computer graphing task on exponential growth. Randall explained his motivation for this shift as the need to address aspects of science with which he was comfortable while teaching on his own: “You need to give me something easy to do while you guys are gone” (P-7/16, 4).

Population Growth Enactment. The enactment of the population growth lesson varied greatly from its original planning. This variation was a direct result of several factors, not the least of which was the definition of science held by Randall. As planned, this lesson was preceded by a homework assignment in which students were to place pennies into stacks with each subsequent stack twice as tall as its predecessor. Prior to this activity, the students had no prior class experience in exponential or mathematical functions. This assignment, then, was designed to allow students to see the results of an exponential function firsthand, and to translate it into a graphical representation.

On the day of the lesson, Randall quickly de-emphasized the penny assignment. When informed that some students had difficulty finding enough pennies, Randall told the students that they could complete the assignment at a later time. Only passing references were made to this assignment task during the rest of the period. In class, approximately ten minutes was spent in a small group activity where the cell division and the resulting population growth from a single bacterium was modeled using calculators, with the graphical results to be recorded in the science journals. Much like the penny assignment, however, this activity was fully completed by only half of the students during the allotted class time. Randall, becoming uncomfortable with the decreasing amount of time remaining for his lecture, asked the students to stop their work so that he could continue with his agenda: “I hate to break in, but we’ve got a lot of other stuff to do” (C-9/26, 4).

The majority of class time (close to 90 minutes of the 120 minute class period) was dedicated to Randall’s presentation of population growth. This lecture was speckled with questions and comments from the students, but was largely directed by the instructor. His questions were posed rhetorically and without pause, controlling the flow of information and ensuring that his intended point was achieved. The presentation was aimed at showing the implications of human population growth, piecing together the idea of exponential growth from the penny activity and the graphing exercise, and then showing graphs of lynx (a predator) and hare (the prey) populations. Randall carefully pointed out that the lynx does not determine the population of the hare, but instead the relation is reversed: the hare’s population, as determined by food supply, causally affects the lynx population. More importantly, while the hare population increases exponentially at first, nature limits such growth (through a limited food supply) and causes the population to decrease. “This is a catastrophe when the line comes down, this is untold suffering; because that means many more in the population died than were born into it when that slope comes down” (C 9/26, 2-3). Randall extended this idea by having the class review graphs and an article describing human population growth. In the lecture after this review, he emphasized the point that humans, armed with a grasp of some scientific concepts--exponential functions, population growth, and limited natural resources --should be able and motivated to avoid uninhibited growth. In this excerpt, Randall drives home his point:

> Before you die, what's going to happen to the human population? It's going to almost double from 5.7 to almost something over 11, between 11 and 12 billion. While you're alive, the human population as far as our best guess or estimate, is going to be doubled during your lifetime. What do you think is going to happen? This is why you need to think about the future! What do you think is going to happen when we have twice the number of humans on earth that are now on it today? (C 9/26, 5)

The class ended with a discussion of how humans must deal with and limit such growth. Unusual in Randall's teaching, this final discussion was student centered, in which students asked questions of one another as they worked to make sense of the ideas Randall had presented. The attempt for synthesis was Randall's apparent instructional goal and after class he voiced his pleasure with the direction the discussion had taken.

<u>Making Sense of the Population Growth Planning and Enactment</u>. The population growth lesson portrays the clash of the motives for teaching and definitions of science between the group and one of its members. In this clash, the goals of the group were circumnavigated, resulting in the direct translation of Randall's views of science into practice. Randall's motivation for teaching about population growth and humanity's interaction with the natural world was based on his personal goals for science instruction (converting students from anthropocentric to ecological perspectives) versus the integrated view of science promoted by the group. While Randall did not entirely disagree with the perspective of the group and initially acknowledged the importance of exponential functions as an integrating aspect of science, his personal interests overwhelmed the initial objectives. Thus, what began as an integrative episode on exponential function became a episode devoted to population growth.

The initial goal of discussing population growth was to place it within the context of ecosystems, or mathematical relationships, highlighting the integrative nature of the sciences. The fact that Randall planned and taught this lesson as an individual was enough to shift it from one of integration to a discussion of humankind's disruption of the environment. Activities originally planned by the group and considered central to content development were changed to tangential features of the lesson. Thus, Randall's use of this lesson was to show science as a tool that society can and must use in order for the earth and its biological inhabitants to survive, again reflecting his conception of the ecological relevance of scientific knowledge. In the absence of the influence of the others, this view was given a higher priority than Brian's and Albert's conception of the personal relevance of science knowledge.

In this lesson, Randall's conceptions of the products of scientific knowledge were given voice, and Brian's and Albert's emphasis on the processes of science was lost. Instead of allowing students to construct their understandings through the activities and discussion, Randall presented a final form concept of population growth as a product of science, and pushed them to think about how that knowledge should be applied in personal and social decisions, such as voting or birth control. While this goal was a worthy pursuit, Randall's teaching served to sacrifice the idea of using the exponential function concept as a part of an integrating theme developed through experiential knowledge, resulting in an isolated lesson and breaking the overall continuity of the course.

Light

Light Planning. The light/spectroscopy unit was selected to portray Brian's role in the planning and enactment. While Albert was the first to propose inclusion of this topic, unlike the collaborative planning and enactment found in the other lessons, Brian was quickly assigned the responsibility for actually defining the content and the teaching approach. As suggested by Randall: "I guess Brian has enough of a handle on that [the spectroscopy lessons], he'll be able to block out the content on his own schedule" (P-8/15, 1). (Randall's emphasis on the products of science was again evident in his view of lesson planning as an exercise in "blocking out the content.")

The lesson series was intended to provide the students with experience in the science process skills of measurement and observation, and address the integrated nature of scientific knowledge. On two occasions in the planning meetings, Randall explained that knowledge of light and its absorption was essential for understanding the actions of chlorophyll. His description of this relationship and how it should be addressed in instruction, however, remained vague despite his enthusiasm: "Just point out examples of why the different portions of the electromagnetic spectrum are important, physically and biologically" (P-7/16, 6). In a later debriefing session, Randall returned to this idea, lamenting the fact that he had not ordered the filters necessary to demonstrate how chlorophyll absorbs red and blue wavelengths, thus reflecting green. Albert jumped into the conversation, describing how this concept could be accomplished in an activity using a chlorophyll solution and a spectroscope. But, during this conversation, it became clear that Randall did not understand how spectroscopes worked, so Brian suggested that “these are some things we’re going to have to play with first,” before they were integrated into the planning of the class session (P-9/20, 17). The remainder of the limited group discussion surrounding the lesson series revolved around Brian’s animated explanations of the underlying content. Beyond their initial conceptualization, process objectives were addressed in only one short exchange by the group.

Brian’s intent was to build from the idea of light and its reflection as introduced in the prior astronomy session by asking the question, “How do we know about the planets and stars that we are studying?” The answers to this question would lead to a discussion of light, the visible spectrum, as well as the entire electromagnetic spectrum of light, in order to introduce spectroscopy (P-9/20, 11). It was only after Brian selected the instructional activities from this integrated and process-oriented framework that the more content-focused objectives emerged. The activities included: 1) The use of a spectrometer to measure light at various distances from the source. 2) The use of a laser and chalk dust to observe the movement of the light beams. 3) The use of a prism to separate out the various wavelengths of light. 4) The use of filters with a light source to demonstrate the additive and subtractive aspects of light. 5) The use of colored Plexiglas and spectrometers with a light source to measure how some wavelengths of light fall off as a function of the thickness of the material it passes through. The final content objectives were to demonstrate that: light travels in straight lines, white light can be split into its component parts using a prism, and that there are additive and subtractive aspects of light.

Light Enactment. The enactment of the light unit lasted for two sessions, alternating between well-organized mini-activities and brief discussions led by Brian. On the first day, Brian recalled a previous discussion of the moon observations, light reflections, and the color seen in sunsets. In this whole group setting, students were already of an inquiring mind set, comfortable and eager to volunteer questions of their own; e.g., “Is that why, when there are clouds in the sunset or sunrise, they are red?” (P-10/10, p. 4). Following this introduction, Brian displayed a number of photographs he had taken, explaining that these photographs were “why I am interested in light.” Students viewed the pictures and were urged to suggest observations and questions about the use of light and shadows in each. The remainder of the class session was then spent in a series of small group investigations, mirroring those Brian described in the planning sessions.

At the beginning of each activity, Brian posed a question such as, “When doesn’t light move in a straight line?,” inviting the students to use the materials provided to make observations, collect data, explain what they observed, and negotiate their explanations within the group and against the data. Occasionally, one of the course instructors (usually Brian, but Christine and Randall were also involved) would help the group refine their observations or organize their thinking. This was accomplished through suggestions such as “Try using that prism in the sunlight instead of the lamp,” or a questions such as, “How do those angles of reflection compare to one another?” (FN-10/10). In this manner, the students determined for themselves the various characteristics of light. To close the unit, Brian related the ideas generated back to previously explored concepts in energy.

<u>Making Sense of the Light Planning and Enactment</u>. The analysis of the light/spectroscopy lessons again portrays the direct translation of the conceptions of science and course goals by of one of the course instructors, Brian. Through this series of two lessons, Brian fulfilled multiple objectives while providing students with hands-on, inquiry-based activities concerning light. First, Brian understood such activities to be pedagogically sound, allowing students to see how light behaved under a variety of student-imposed conditions and to learn the scientific material in a meaningful way. Second, students were exposed to the nature of science through their participation in the science-oriented, inquiry environment. Students worked in a social arena in their small groups, using instrumentation to make measurements and describe natural phenomena. Students came to understand science concepts by observing and deliberating over the observations firsthand. Brian’s pedagogical efforts were in the background as a resource to guide their thinking. In Brian’s view, such instruction emphasized both the concepts of light as well as the nature of science.

Although the processes of science were emphasized, Brian expected the students to learn content as well. Through the activities, the students were to construct scientifically valid explanations for the phenomena they encountered. Brian was careful to integrate the material into the overall content of the course, drawing on connections across topics in both the introduction and closure activities. With the expectation of a short discussion of the nature of photosynthetic pigments by Randall, however, few attempts were made to integrate the material across the scientific disciplines.

The importance of the personal relevance of science was vividly portrayed when Brian revealed a significant aspect of his personal life through his photographs. Through this, he demonstrated his personal applications of the concepts of light. Brian created additional opportunities for personal relevance through his careful selection of student-centered activities, providing a motivation for students to ask and answer questions about the content.

The Impact of the Instructors' Definitions of Science on Course Planning and Enactment

The instructors' case studies and the description of the planning and enactment of the three instructional episodes demonstrate how definitions of science were translated into instructional events. As shown in figure 2, the planning and enactment of the journal allowed for a clear translation of group goals, potentially due to the care and effort taken to craft this assignment. Of particular note was the translation of goals related to the processes of science through data collection and analysis efforts. This assignment also provided a context for creating personal relevance and the integration of knowledge, although the process aspect was the most explicitly addressed aspect of this assignment. Despite the limited input of the group, the light episode also faithfully represented the conceptions of science held by both the group and Brian. The lessons were infused with an overall emphasis on student inquiry and the use of process skills to generate science knowledge. Secondarily, these lessons also housed opportunities to develop the importance of the personal relevance of science and to a lesser degree they provided an opportunity for integration. This pattern of full to limited congruence of teaching practices and course goals was broken, however, in the population growth episode. In this episode, the tangential goals of Randall superseded the group's goals. In this case, little if any attempts were made to integrate the course content, students' experiences with concrete representations of science conceptions were sacrificed to didactic instructional tools, and issues related to ecological relevance dominated those of personal relevance. Randall's view of ecological relevance opposed the group's emphasis on personal relevance, as he wanted his students to view science from a grander, less individualist scale.

Insert Figure 2 about here.

The intersection of the instructors' definitions of science and the planning/enactment of specific teaching episodes highlights the influence of individual beliefs on teaching practices, a relationship also documented by Yerrick, et al. (1997) as they described how teachers interpret descriptions of teaching in order to fit in with their pre-existing sets of beliefs. So, given the strong relationship between beliefs and teaching, how faithfully did the enactment of *The Natural World* represented the course goals?

Learning science through the use of science process skills was evident both in the planning and enactment of the science journals and in the light episodes. While the role of process skills and active student learning clearly varied by instructor and their personal beliefs about the best way to learn science, opportunities for student data collection and collective sense making in order to construct science knowledge were found. In addition, the course was largely based on small group interaction in an effort to encourage group consensus when making sense of data and generating science explanations that integrated physical phenomena and prior knowledge. This group work and the keeping of a science journal were viewed by the course instructors as direct translations of the activities in which scientists engage, and therefore acted as another mechanism to convey their definitions of science. However, Randall's definitions of science as complex and ecologically relevant directly contrasted with the definitions reflected in the course goals, and this clash was reflected in the teaching episode. Thus, in the population growth episode, we have direct translation of many aspects of Randall's definitions of science but a contradictory translation of the goals of the course.

The relevance of scientific knowledge was also differentially addressed depending on the instructor. Brian and Albert prized the personal relevance of science and used this value to structure teaching experiences to foster similar understandings in students. For Randall, personal relevance was sacrificed at the expense of the ecological relevance of scientific knowledge.

Another course goal that was unevenly addressed was the integrated nature of scientific knowledge. While the structure of the course and the journal assignment sought to emphasize this point, the integrated nature of science was often pushed to the margins of the content. For instance, when Brian structured lessons about light, chlorophyll was only briefly mentioned and light was only approached using a physics lens. However, thematically across the broader content of the course, light was connected to other course topics. When Randall taught about population growth, potentially integrating concepts were completely omitted and no effort was made to mesh the topic into the overall flow of the course. While integration was an important course goal, aside from the journals, as shown in figure 2, this was not a central aspect of course enactment.

While goals related to the nature of science (i.e., science is tentative and situated in a social, cultural, and historical context) were discussed in the planning sessions and had a home in an early unit, little evidence of their continued emphasis (either implicitly or explicitly) could be found in the instructional episodes that were analyzed. While the instructors held sophisticated conceptions of the nature of science, this aspect of the definition of science was ignored and after its early introduction, limited efforts were made to teach this content.

Students' Definitions of Science

Based on this course, what conceptions of science did the students take away? Students' conceptions related to the definitions of science are grouped below under three categories: process, product, and science as a way of knowing.

Process

Most of the students recognized the strong course emphasis on the processes of science:

> - [In this class] I learned a lot about research and being in the field, observation skills that I just didn't get in my other classes...Most of those [other courses] are just learning things in the book; this was learning how to find out things, how to observe. (EI, Q22)
>
> - I didn't learn as much about specific scientific concepts, but I think I did learn more about science and how to do it....This class wasn't like memorizing what does what or how it works, it's more like, observe things and why you think it works rather than 'it works' and 'this is why.' (EI, Q2)

Others described the way in which the course allowed them to hone their problem solving abilities:

> - [Figuring out how to answer a question] was the important thing, to go about it in a logical information. The information was almost incidental. (EI, Q1)
>
> - More creative thinking [is] going on [in this class], you know, whereas in most other science classes you memorize a formula and spit it back out. It's more like a math class than anything else, and this was more like you try and do actual thought. (EI, Q17)

As shown in these interview excerpts, the students recognized the process approach used in the course and felt that they had gained skill in collecting and analyzing data in problem solving situations as a means to learn science content. Unfortunately, they failed to recognize that, through using these processes in the quest to solve problems, they were also learning to do science. Based on these responses, it seems that the students saw the processes of science as more of a pedagogical tool than one of the process of generating science knowledge.

Product

Related to students' recognition of the process orientation of the class, they also recognized that the detailed products of science were de-emphasized:

> I think the idea of this class was to get a basic understanding of a few concepts, and I think if that's the goal, that's what I got, and I hope they weren't trying to impart a whole lot more knowledge than that. (EI, Q9)

The decreased emphasis on quantity of content information was purposefully made by the course instructors in order to highlight science processes and the integrated nature of scientific knowledge. Integration, however, was not recognized as fully by the students as the instructors had intended. When asked to describe the course, students were more likely to talk about personal relevance and awareness of science rather than discuss the interconnectedness of scientific knowledge. For instance:

> I went to a basketball game with one of my daughters, and instead of really looking at the game and rooting for the players, I was watching to see the distance between the shots, like someone would slam dunk it, and [I would look for] how long it took to fall. I was kind of like [collecting] some data. (EI, Q6)

Indeed, although several students recognized the effort at integration (e.g., "[the instructors] are adding all the sciences together" (EI, Q15)), many comments provided evidence of continued disciplinary segregation. For many of the students, each of the professors represented a separate science discipline with a separate approach to understanding the natural world: "Brian is more in physics and Randall is more in biology, so with Randall it is like he kind of brings Brian down so you can understand what he is saying" (EI, Q26). Despite this recognition of disciplinary allegiances, the course did help students identify content connections:

> It's common sense that you know that everything is interrelated and science is interrelated, and this class I guess showed you specific examples of how everything is interrelated, like humans with the

> environment, and the environment with the different parts of the environment. I mean, I've always known that things are interrelated, but I guess this class, like made me realize it more specifically. (EI, Q4)

Great gains were made, however, in seeing *the world* differently after having taken this course, even if they didn't mention that they viewed *science* any differently. Both aspects of personal and ecological relevance could be found in student's assessments of the course:

> [This course] makes us aware of things that are around us." (EI, Q36)
>
> [This class] gives me a better understanding of why I should and shouldn't do things. Why things take place and why they don't take place. (EI, Q21)
>
> [This class] changed the way I looked at things because now I understand how they work. Like trees -- I see cells and photosynthesis. It kind of scares me. (EI, Q30)
>
> [I learned that] there are these ideas and concepts out there that we all take for granted that we don't understand that are really cool, and really interesting, fascinating issues. (EI, Q33)

Science as a Way of Knowing

Student exit interview comments focused on what was taught and learned in the course, but students were not explicit in their transfer of these ideas to the general characteristics of science. Not surprisingly, no direct statements were made related to the nature of science such as, "I learned that science is tentative," or "Science is a social activity." Without more direct measures of student views of the nature of science, few conclusions can be drawn. The research literature in this area, however, suggests that, in the absence of explicit instruction in this area, few gains were likely.

Summary of Students' Definitions of Science

Overall, as shown in Figure 3, the students recognized the strong process orientation of the course and gained an appreciation of problem solving opportunities and applications of science knowledge in their daily lives. The course emphasis on integrated scientific knowledge, although apparent, remained fragmentary with each of the three course instructors embodying the boundaries of the distinct disciplines of science. It is possible that this result is a non-negotiable consequence of teaming, a structure imposed by the need to draw on diverse content knowledge. Perhaps most successfully, the students gained an understanding of the personal and ecological relevance of scientific knowledge. Unfortunately, the course failed to help students understand how their learning in the course was similar to the way in which knowledge was constructed in science: "[The course instructors] let you do it, they let you observe, it's almost like being a scientist" (EI, Q7). Class participation was *almost* like being a scientist, but not quite.

Insert Figure 3 about here

Conclusions

The purpose of this study was to answer the question: How and why are scientists' definitions of science portrayed through their teaching in a reform-based college science class and how are these definitions perceived by students? In this study, we documented two patterns of translation of scientists' definitions of science into curricular enactment. With the case of Albert's journals and Brian's light/spectroscopy units, we see how scientists' definitions of science are woven into the goals of the course and, subsequently, how these definitions are directly translated into curricular enactment. With the case of Randall's population growth unit, we see how an individual's personal definition of science conflicts with the goals of the course but eventually impacts curricular enactment. Each of these cases demonstrate the powerful effects personal conceptions about science have on curricular enactment, conceptions that may be little transformed by discussions of reform (Yerrick, et al., 1997). In this study, personal definitions of science, even in the absence of structural and institutional barriers, compromised attempts to reform teaching practice and resulted in the even achievement of course goals. In the following section, we will explore the reasons contributing to a well intended, yet uneven, attempt at reform.

How do instructors' definitions of science shape the manner in which they teach in a reform-based classroom?

The definitions of science held by the instructors in this course were sophisticated yet varied. Albert was committed to the view that scientific knowledge was integrated, personally relevant, and best learned in problem solving situations in which students engage directly with the phenomena of interest. Albert reveled in the tentative nature of science and was fascinated by the multiple strands at differing levels of magnitude that could be explored when examining any topic. Brian held similar convictions about the importance of science processes and the recognition of the personal relevance of science in the doing and learning of science. Different than Albert, however, Brian had a more narrow range of content expertise and so had a lesser emphasis on the integrated nature of scientific knowledge. In contrast, Randall saw science teaching as an opportunity to convert students from their anthropocentric views and instill in them the ecological relevance that science provided for him. For Randall, the process of generating complex scientific knowledge was beyond the grasp of his students, leading to an emphasis on crafting elegant stories that tied together the content of science and downplaying students' efforts in generating that knowledge.

Our results demonstrate that the scientists' definitions of science directly impacted course instruction. While this relationship has been well described for primary and secondary teachers (Laplante, 1997; Yerrick, et al., 1997; Yerrick, et al.,1998), this research is one of the first to document such patterns in scientists. When extended opportunities existed for group consensus around an instructional approach, such as the use of journals within the course, the multiple views of science held by each of the scientists were blended into a single entity and, so, the goals of the group were largely met. When group planning and implementation was left to the responsibility of a single member of the team, as was seen in the light and population growth teaching episodes, the definitions of science held by the individual instructor were portrayed. In the case of Brian, his definitions meshed well with the goals of the course but with Randall, there was substantive conflict.

How are the definitions of science described by reforms translated into college level science instruction?

This course acted as a best case scenario for the implementation of reform with the removal of many of the barriers commonly associated with foiled attempts at reform and a high presence of those factors that stimulate reform. For instance, the instructors for the course were knowledgeable, motivated, and willing to explore teaching the course in a new manner as stimulated by the science reforms. Bingham is a college dedicated to small class sizes and excellence in teaching, therefore making the class design efforts in line with the institutional reward structure. Through the grant, they were awarded with the time, money, and support staff to adequately prepare and implement the course. In designing a Liberal Education course, they had few curricular constraints, expected outcomes, or mandatory assessments, allowing for freedom in content and pedagogical design. Based on these advantages, it could be expected that course goals regarding the portrayal of the definitions of science would translate directly into practice, but this was not the case. Why? Some of the answers lie in the previous section: for direct implementation of course goals, there must be convergent definitions of science as well as similar philosophies of science teaching held by each of the course instructors. Other answers to this question are more subtle and relate specifically to the goal of science content integration.

Content integration was one of the primary goals of this class, but as shown in figure 2, it was one of the more elusive. Despite the broad content preparation of Albert and Randall, it was difficult for them to find the content and pedagogical tools to make integration a reality. Long conversations and specific attempts to address the various overarching science topics in the classroom ultimately resulted, not in student recognition of the strong interconnections of science, but in students identifying the disciplinary roots of the individual instructors. This outcome can be seen as a flaw in the enactment of the curricula, in which the explicit message conveyed the integrated nature of science but the implicit message (portrayed through individual instructors being responsible for the content of their specific disciplines) supported the separation of the various disciplines. Alternatively, this student outcome can also be understood as an indictment of the goal of content integration. Scientists, with advanced knowledge in their field, are perhaps the best individuals to find and illuminate linkages among science disciplines. If these prepared individuals were incapable of portraying content integration, what is the hope of effective portrayal of integration by typical classroom teachers? Can science best be learned in an integrated manner, or is there validity in the maintenance of disciplinary roots?

Also of concern is the manner in which the nature of science was ignored in instruction. Much like one of the teachers described by Schwartz and Lederman (2000), explicit instruction regarding NOS was relegated to an unit early in the course. In the teaching episodes analyzed, NOS issues were not a focus of instruction. This omission is significant given the scientists' intent to emphasize this aspect of the definition of science and given their own sophisticated conceptions for this construct. This omission demonstrates that these scientists understood isolated instruction of NOS to be an appropriate means of instruction.

<u>How are student definitions of science impacted by efforts at reformed teaching practice?</u>

The enactment of the curriculum resulted in the several positive student outcomes. Upon leaving the course, students had an understanding of the personal and ecological relevance of scientific knowledge and they came to recognize and refine their science process skills. Unfortunately, several of the course goals related to the manner in which science is defined were not achieved by the students: they failed to grasp the integrated nature of scientific knowledge and, while they understood their own role in personal knowledge generation, they did not translate this to recognize science, too, as a process of knowledge generation.

What accounts for this indirect translation of the definitions of science to students, even though this was a major course goal? Despite their rich content knowledge, much like one of the secondary science teachers in the study by Lederman and Schwartz (2000), these three scientists had limited pedagogical content knowledge for teaching the definitions of science. Additionally, the three scientists used similar, and sometimes contrasting, definitions of science. This lack of uniformity may have contributed to the uneven gains in students' understandings. Finally, we know that implicit instruction regarding the nature of science is not effective (Lederman 1992, 1998; McComas et al., 1998; Abd-El-Khalick, et al., 1998). While an explicit unit on the nature of science was featured early in the course, in later units, these ideas were no longer a focus of instruction. Certainly, in the three instructional episodes we targeted, instruction regarding the nature of science was largely implicit if it occurred at all. It is noteworthy that the early explicit emphasis on the definitions of science seemed lost to the students in the subsequent instruction. Perhaps the cognitive load based on competing purposes of the course was too severe for students, allowing them to dismiss what seemed to be the less important definitions of science. Thus, even in this reform-based class, knowledge of the products of science overwhelmed students' knowledge of the process of science. While the reforms call for the meaningful portrayal of both the broader definitions and products of science, such a balance was not achieved in this class. We argue that discussions of reform must move beyond the rhetoric of balance toward systematic investigations determining if and how such a balance can be achieved.

Implications

Several implications exist for our findings. First, the reforms define science in a tripartite manner as process, product, and a way of knowing. It was assumed that each of these instructors shared this reform-based definition because of their content expertise and willingness to work on this project, but this failed to be the case. Additionally, the reforms carry with them an underlying set of assumptions about the teaching and learning of science. For instance, the definitions of science described in reforms can only be portrayed in a context in which the teacher views students as capable of learning by exploring and making sense of science phenomena. This assumption was parallel with the beliefs of Albert and Brian, but not Randall. The absence of a common definition of science and science teaching/learning prevented direct communication between all members of the instructional team and resulted in uneven attempts at implementing the course goals.

Our findings demonstrate that reform-based teaching often involves a change in fundamental beliefs about the definition of science and about teaching and learning and these beliefs are difficult to change without sustained effort and external facilitation. As scientists, the language of teaching and reform was outside the experience of these well-intended instructors. Without detailed knowledge of the consequences of teaching beliefs on practice, there were no opportunities to explore fundamental beliefs and examine how the conceptions of each individual compared with those of the group and compared with the stated goals for the course. For such a conversation to occur, a science educator would be needed as part of the team to facilitate such discussion. As conceptual change theory would explain (Strike & Posner, 1992), without making explicit the goals of the course and the conceptions and beliefs of each of the instructors, little change in personal understanding and curricular enactment can occur.

Because of this need for sustained effort, reflection, and external facilitation, we suggest that the time frame for support of such curriculum development and implementation projects be extended. Even if there was a recognition of the need for a common level of understanding about science and science teaching, the summer of course development supported by NSF would not have provided sufficient time to come to this consensus as well as simultaneously plan and implement the course. With periods of implementation time extended to five years, versus the more common funding pattern of 2-3 years, it might be possible for a development team to converge in their understandings. This would allow implementation grants to serve both as a means to develop a novel course as well as allow for the development of the beliefs and practices of the instructional teams that participate in such development.

It must be recognized that change in conceptions of science teaching can only occur in willing participants. When seeking team members to institute reformed teaching, it would be important to examine the initial views held by the potential team members and assess their willingness to thoughtfully reflect on their understandings and teaching practices. As we have recognized with our students, explorations of the definitions of science requires carefully selected experiences and explicit discussions with a knowledgeable teacher. We argue that scientists, while they have a wealth of knowledge about science, are like our students in that they need exposure to appropriate teaching practices and scaffolded discussions to develop their pedagogical content knowledge for teaching about science.

Finally, the exploration of this course uncovers the difficulty in planning and enacting an integrated science course. However, granting institutions often request dissemination efforts as the end products of support. Our findings cause us to question the utility of such efforts. If course enactment was so difficult for content experts who had devoted a considerable amount of time and energy to the project, how can curricular materials be useful for those less familiar with the project? While prepared curricula may contain descriptions of what and how to teach, our findings demonstrate that much of teaching depends on underlying knowledge, assumptions, philosophies of science and teaching and learning—-important pre-requisites to teaching that such materials cannot adequately address.

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Table 1: Frequency of Instructional Activities Employed

Nature of Activity	Percentages of Class Time
Lecture	22%
Discussions	
Triadic dialogues	24%
Student centered	0%
True debate	0%
Small group	15%
Video	6%
Field Trips	0%
Demonstrations	4%
Hand-on, Small-group activities	25%
Writing	1%
Quiz/exams	3%

Appendix A

Sample Questions from Instructor Interviews

1. We are interested in your academic history and teaching background. How did you become interested in science? Where did you go to school? What aspects of science interested you and why?
2. What about your content area captured your interest?
3. What were your classroom experiences like in you K-12 education? In college?
4. What research experiences did you have prior to graduate school? What experiences did you have in graduate school? How would you characterize those experiences?
5. When did you first think about teaching science? What were your first teaching experiences like? How would you describe your teaching?
6. How did you balance the demands of research and teaching in graduate school? How have you balanced those demands as a faculty member?
7. What courses have you taught since coming to Bingham?
8. What experiences have impacted the manner in which you teach? What aspects of your life or work informed or influenced your teaching practice?
9. What aspects of your content influence your teaching? What aspects of science are important for students to understand?
10. How do your students influence the way you teach?
11. Has your science teaching changed since your early teaching experiences? In what ways? What caused these changes?
12. What are your general goals for teaching science? What are the goals for the students in *The Natural World*?
13. What are your biggest successes in the class to this point? What are your biggest reservations about the manner in which it has been taught?
14. Has being involved in *The Natural World* impacted your teaching in other classes? How?

Appendix B

Sample Questions from Exit Interviews

1. What science classes have you had in high school? In college? Describe them.
2. Is this class very similar or different than the science classes you've had in the past? How is it different? How is it similar to those other classes? How does it compare to your other college courses? What aspect of this class did you particularly enjoy? Find difficult? Find rewarding?
3. What was the most important thing that you learned in the class?
4. Did the field experiences add to what you learned in class? How so? If not, why?
5. What was your opinion of the small group aspect of this class? Did you enjoy it? Was it difficult for you? Why/why not?
6. What was your opinion of the writing component of this class? Did you enjoy it? Was it difficult for you? Why/why not?
7. What did you find to be the primary source of the information you learned in this class?
8. What class activity stands foremost in your mind? Why?
9. Do you plan to take the second semester course? Why, why not?
10. Would you recommend this course to a friend? On what basis would you make this recommendation?
11. If you were preparing a friend to take this class, what would you tell them?

Appendix C

Analysis Questions for the Planning for an Instructional Episode

1. On how many occasions was it discussed?
2. Who originated the idea?
3. What were the original goals/instructional objectives for the episode?
4. Who took the lead in planning the episode?
5. How did the planning for the episode change over time?
6. What were the final goals/instructional objectives for the episode?
7. What were the major points of conversation about the episode? Who were the major players in these conversations? What were their personal motivations behind what they were saying? What was the evidence for this?
8. Describe how the event was to occur.

Appendix D

Analysis Questions for the Curricular Enactment

1. Who is primarily responsible for the teaching? Who else was present? What was their role?
2. What was the context of the instruction? How long did it last? What topics proceeded it? What topics followed it? How much does the instructional pull from or rely upon ideas already presented in the course?
3. What were the enacted instructional goals of the episode?
4. What was the nature of instruction used in the instructional episode?
    a) inductive or deductive.
    b) teacher centered or student centered (who was in charge of organizing information and constructing explanations?)
    c) what instructional strategy was employed?
        activity,
        lecture with/without demonstration
        video,
        whole group discussion (triadic dialogue, true discussion, student debate) (Lemke, 1990)
        small group discussion

Figure 1. Relative degree of congruence between the course goals related to the definition of science and the instructors' personal definitions.

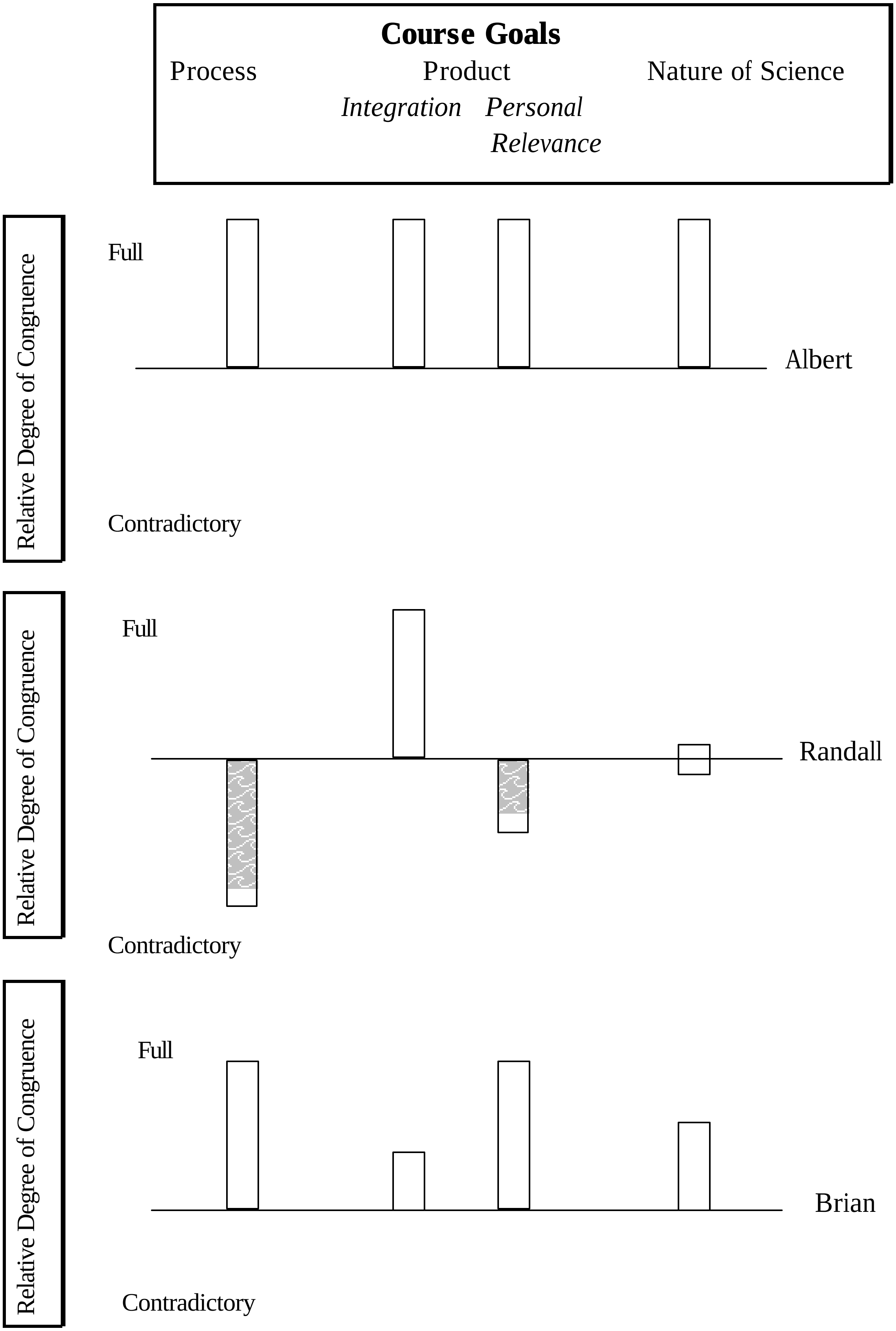

Figure 2. Relative degree of congruence between the course goals related to the definition of science and the teaching described in each episode.

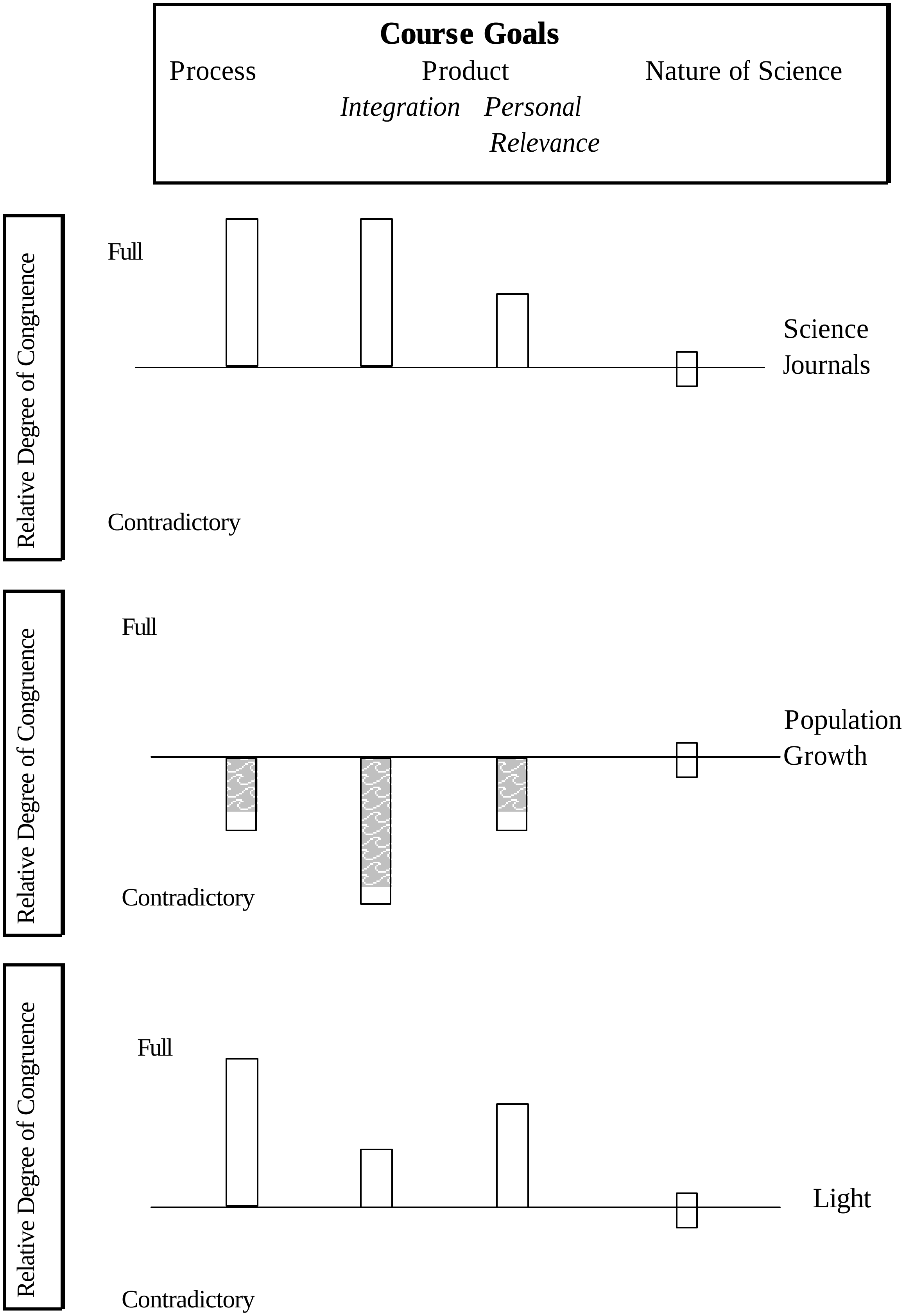

Figure 3. Relative degree of congruence between the course goals related to the definition of science and students' personal definitions.