STUDY DESIGN

Participants

The present study is based on a mostly unanalyzed part of an extensive data base on students' experimenting, knowing, and learning in high school physics at a private, all-male school. Data were collected over a period covering two school years (see Figure 1 below). During the first year, 46 students distributed over three sections enrolled (four spent four-month periods overseas) in a junior level qualitative physics course. Twenty-three students (one of whom dropped the course about four months into the school year) continued and enrolled in one of two sections (11 and 12 students, respectively) of a senior level quantitatively-oriented physics course; one new student in the school also enrolled in this course. This study focuses on the remaining 23 students' discourse regarding scientific knowledge and truth. The students were typically from well-to-do homes of varying cultural origin (6 Asians, 4 Europeans, and 13 Anglo Saxons), but in academic terms, comparable to the students in surrounding public high schools. Students typically had not chosen physics because of an interest in the subject per se. Rather, sometimes encouraged by their parents, sometimes on their own, they had chosen the subject to keep their career choices open by complying with the regulations of nearby universities for getting into specific programs. After completion of high school, only six of the 23 students enrolled in science- or engineering-related fields. Most students opted for careers in business, law, or general arts.

The special situation of the school provided for a distinct group of respondents, which is a goal of interpretive research. Such distinctiveness of group identity allows for replication or comparison with distinctly different groups, and is the equivalent of experimental control in natural settings. The chief characteristics that made this population different from students in a public school were gender and the fact that all students were college or university bound. A third distinctiveness was the nature of the physics course in which the students were enrolled and which is described below.

Roth taught all physics courses during the two-year data collection. His preparation included a MSc in physics and a Ph.D. in science education, research experience in both fields, and 10 years of experience teaching science, mathematics, and computer science. As all teachers in the school, he participated in the daily, compulsory extra-curricular and sports programs. Weekly evening study supervision (7-11pm) and academic advisor duties provided additional opportunities for talking with students about topics relevant to the study and for building a relationship of trust.

Classroom Context

Classroom ecologies are so complex that it is not clear which aspects (teacher, student, textbooks, learning environment, curriculum) contribute to students' understanding of the nature of scientific knowledge or how they contribute (Lederman, 1992). We therefore provide descriptions for those aspects of this classroom that are likely to have contributed to changes in students' discourse over time.

Curriculum

Physics was a distinctive course that differed from traditional physics courses in many respects. It emphasized the process character of knowing and learning physics: there were many opportunities for students to interact with each other to make sense of natural phenomena; defending one's choices of experiment, and discussing experimental and interpretive differences were valued over "getting right answers." Experiments made up the core of the activities around which the rest of the course revolved (70% of class time). Most experiments were designed by students themselves around phenomena of their interest related to the current curriculum topic (for a sequence of the topics see Figure 1). Students were asked to provide convincing arguments—convincing to both peers and teacher—for the reasonability of chosen research problems, appropriateness of research designs, and soundness of the interpretation of collected data. The goal of instruction was not to have every student do the same routine investigation but to create classroom communities in which interesting phenomena, successful technologies, and meaningful and interesting knowledge would be propagated from group to group. Whatever activity students engaged in, they were provided with the situated (context-dependent) support that they sometimes needed in order to complete a particular research project. There were repeated instances in which neither teacher nor laboratory assistant (with an MSc in physics and six years of research) had an explanation for students' data. In these instances, the teacher and laboratory assistant engaged with students in a collaborative inquiry, frequently joined by students from other groups. In one situation, students could not make sense of the data from their experiment involving yo-yos. When the "experts" could not answer students' questions, the entire group began to generate and test a series of hypotheses. Here, students participated in an inquiry for which the "experts" did not have a ready answer; scientific knowledge was portrayed as tentative and uncertain.

The remaining 30% of classroom activities consisted of discussions concerning experimental results, readings on the nature of science and objectivity, introductory demonstration and modeling of scientific instrumentation, and discussion of textbook-related activities (all of which students completed as homework). The physics laboratory was an open learning environment accessible to students and teachers at all times (unless it interfered with the activities of the class currently scheduled). Many students made use of the laboratory and its facilities during their spare periods, after school, in the evening, or during the weekend.

In addition to their experimental and text-book related activities, students also read selected material relating to epistemology (e.g., Bateson, 1980; Suzuki, 1989). They reflected on these readings in written essays which were followed up by whole-class discussions. During the first term of their senior year, students of the two sections of senior physics read 11 of the 15 chapters of "Inventing Reality: Physics as Language" (Gregory, 1990). Students completed five reflective essays, each followed by a class discussion. After completing the book, students studied the units on the wave and particle nature of light and matter as part of their regular curriculum content. Subsequently, students wrote an essay in which they were asked to reflect on the nature of light based on their readings of "Inventing Reality" and textbook-related experiences.

Epistemology in Students' Readings

Epistemology-related material read by students during their junior year included selected chapters from Bateson's (1980) "Mind and Nature: A Necessary Unity" and Suzuki's (1989) "Inventing the Future: Reflections on Science, Technology, and Nature." The nature of the authors' stance to knowing is best expressed in the following quote from one of the readings:

> Epistemology is always personal. The point of the probe is always in the heart of the explorer: What is my answer to the question of the nature of knowing? I surrender to the belief that my knowing is a small part of a wider integrated knowing that knits the entire biosphere or creation. (Bateson, 1980, p. 93, emphases in the original)

Students who enrolled in senior physics read, as an integral part of their program, "Inventing Reality: Physics as Language" by Bruce Gregory (1990), the associate director of the Harvard Smithsonian Institute of Astrophysics. The views of physics expressed in this and the students' textbook, because they constituted an important aspect of the students' learning environment, are outlined in the following paragraphs.

"Inventing reality: Physics as language". Roth chose this book because it was consistent with social constructivist understandings developed in science studies (e.g., Knorr-Cetina, 1981; Latour, 1987). It thus appeared to be a useful but alternative companion to the textbook which emphasized a traditional view of scientific knowledge. In the opening statement of the preface, Gregory (1990) outlines his program and sets the tone for the remainder of the book:

> Physics has been so immensely successful that it is difficult to avoid the conviction that what physicists have done over the past 300 years is to slowly draw back the veil that stands between us and the world as it really is—that physics, and every science, is the discovery of a ready-made world. As powerful as this metaphor is, it is useful to keep in mind that it is a metaphor, and that there are other ways of looking at physics and at science in general. (p. v, italics in the original)

The author further explains that the book (a) tells a story of how physicists invented and improved languages to talk about and describe the world, and (b) explores the relationship between language and the world—where "language" includes all forms of scientific representations such as mathematics, diagrams, and words. In his account of how physics-related languages were invented, developed, and discarded, Gregory only touched on highlights rather than delving into historical details and caveats. Following Quine (1987) and Rorty (1989), Gregory portrays the relationship between language and world as contrived; the choice between competing language games is always made on pragmatic grounds.

"Fundamentals of physics". The students' textbook "Fundamental of Physics: A Senior Course" (Martindale, Heath, & Eastman, 1986), approved by the Ministry of Education, is a 825-page compendium that stresses the mathematical nature of physics. The authors advise readers that "Much attention is given to problem solving" (preface) and that comments following sample calculations "emphasize the method of reasoning" and diagramming "skills." While the text frequently includes adjectives that highlight the tentative nature of initially proposed ideas (such as Einstein's development of relativity theory), the final paragraphs of each chapter present human understanding and mathematical equations in factual terms. Thus,

> But what does this equation relating mass and energy [$E = mc^2$] really mean? In many ways, it means that mass is just another form of energy, and that it ought to be convertible into other more common and usable forms. There are many examples where this conversion between mass and energy can be verified [followed by a list of examples and calculations]. (p. 687-688)

Chapters on wave-particle dualism of nature were developed in a similar fashion using adjectives that underscore the tentative nature of famous scientists' initial ideas (Einstein, Compton, Heisenberg or Bohr "proposed," "suggested," "hypothesized"). But this tentative discourse was always juxtaposed to the authoritative discourse of experimental verification, certainty of observations (even if these dealt with invisible phenomena such as "electrons" or "X-rays"). Thus, scientific investigations "clearly demonstrated"; constituted "conclusive" or "strong experimental evidence"; provided verification if equations were "true"; "actually measured" phenomena; were "exactly explained" by a theory (which often led to a Nobel award); or "confirmed" relationships and "validated" mathematical expressions. The students' textbook, then, provided a classical view of science and the development of scientific theories: scientific knowledge is improved in repeating cycles in which great scientists propose new theories in a tentative manner followed by long periods of experimental testing, confirmation, verification, and sometimes abandonment of initial ideas, theories, and laws in favor of new proposals.

Students repeatedly commented on the difference in epistemological claims made by the physics text and "Inventing Reality." Thus, physics texts "give you the impression that God created the laws, like tablets with equations that describe," "They are telling you, He set this theory and it works like this, and in most cases it is the way it will be, and this is how we use it," or "When we learn a concept such as Newton's laws in a textbook, we are told that his is exactly what is occurring in nature. Bruce Gregory does not take the same approach."

Epistemological Context of Teaching

In this course, Roth took a very personal stance to knowing and learning. Students received continuous feedback on their work, word problems, laboratory reports, and essays. The following excerpt from the feedback to a student essay shows that the teacher allowed for personal dimensions in learning, the dilemmas of learning specific things in the face of their tentativeness, the similarity of the students' laboratory work and that of science ("which provide you with a sense of the tentativeness of the subjects"), and the uncertainty whether traditionally accepted ways of learning physics ("solving word problems") make students better physicists.[1]

> A very personal reflection. I like that even if I don’t always get the best of it. But it is important because it helps me learn more about students and become a better teacher. You make some very important points, particularly with respect to the dilemma in which we all find ourselves: Why study physics if it is tentative? For one, there are areas in physics, such as Newtonian mechanics, which have changed very little over the past 300 years. And there will be little change expected. On the other hand, there are also the labs which provide you with a sense of the tentativeness of the subjects. I have always been unsure if solving word problems will make students better

physicists, if they learn as much about what physics is as they would if they only did projects. (FB4.911108)

The same stance was evident in the class discussions of the readings. These were intended as reflections, opportunities to talk through important and difficult issues in an environment of trust. For the teacher, it was not an issue of indoctrinating students to a different kind of truth but presenting knowing as a personal dimension rather than as abstract truth. This was clear in the opening of discussions, in which the teacher did not ask students about the way of understanding the book, but talked about what he personally understood and what students thought: "What sort of things came up in this reading? The author talked about time. And that is what I picked up from one of the two chapters, time and space. And two questions that pop up are, 'What is time?' and 'Why do we experience time?'" (S1.3.1). In other situations he pointed out the personal dimensions of his own knowing ("I always like to make the distinction between knowledge and information. Knowledge is something that I can know").

Class Discussions

In these classes, the discursive achievements of understanding and collective reflection on the nature of science in students' past and present experience were central. The positive atmosphere allowed students to elaborate new ways of talking about knowing, learning, and understanding. Even naturally reserved students, such as Tony, with a penchant for right answers, began to contribute significantly to the discussions and to test new ways of talking about the nature of knowledge. The following episode exemplifies the class discussions (S1.5 911129).

1. Tony: About math, they invented, I think math is there, may be not as you know, "y equal m x plus b" but it's the people who invented the formulas and the basic principles (Tom: discovered them?) Yea, discovered them but they like explained (Tom: described.)—this language barrier again—yeah described what happened in nature, like gravity is one example, no one knows what it is but even the math equations like "force equals m a" it is true in that it describes

2. Roth: But see, the author makes exactly that point that "F equal m a" is only valid in large, for large.
3. Tom: Yeah, it doesn’t work with ah.
4. Mick: Man didn’t just walk along what happened and found math, they invented that, they invented the laws of nature its all been out there.
5. Carl: But Newton didn’t say gravity, it was there, he invented the name "gravity" but it was there, he discovered the force.
6. Jim: Gravity existed, but the fact that the greater the mass the greater the
7. Tony: I don’t think that the greater the mass, it didn’t fall.

In such conversations, Tony elaborated a pragmatic position to knowledge. Although the underlying mechanisms of natural phenomena cannot be known, they can be described by mathematical formalisms; he drew on examples which were part of the shared experience of all students in this class, formulaic expressions for straight lines ($y = m \cdot x + b$) or Newton's second law ($F = m \cdot a$). Mick proposed that laws of nature were human inventions (line 4), while Carl suggested that phenomena existed prior to all human perception (line 5). This was part of a series of episodes during which students achieved the discursive separation of "nature" and "knowledge," which many of them had previously considered to be the same. That is, students tested discursive strategies to talk about knowing without imputing truth to the contents of knowing.

In line with the teacher's understanding of legitimate peripheral participation, students could contribute to the conversations when they wanted, but were not required to do so. Accordingly, some students contributed very little, others more considerably. However, the frequency of any single student's contributions varied within individual discussions and across discussions. Conversations about scientific knowledge, nature, truth, and languages were not limited to the classroom. Frequently, students gathered in their dorms and talked about cosmology. Several read and discussed books such as Stephen Hawking's (1988) "A Brief History of Time." When it was Roth's turn to supervise study time, students gathered around him to engage in discussions which were not limited to physics, but drew on poetry, literature, philosophy, cosmology, and religion.

Data Collection and Interpretation

Data Sources

In the course of the 15-month study, there were different situations during which students could talk or write about scientific knowledge and truth. Following the cited research in social psychology, science studies, and ethnomethodology, we do not consider students' talk and essays to be windows on students' minds, inner worlds of relatively stable beliefs, Self, or world views. We take the perspective of talk as situated action so that our interest here is not in proving or disproving what students "really" think about the nature of scientific knowledge, but how students constituted the veracity and factuality of their claims about knowledge. Here, we were more interested in the interpretive resources they used to support their claims about the nature of scientific knowledge.

Because of this perspective, students' talk and writing have to be understood not just as producing and supporting claims about knowledge, but as doing so in a way that they considered appropriate in the context of required course assignments. Contexts in which students' talk and writing about the nature of scientific knowledge were recorded for inclusion into the data corpus included a variety of structured and unstructured essays, interviews, and class discussions. Figure 1 presents an overview of the curriculum and the data collected over a two-year period involving these students.

[INSERT FIGURE 1 ABOUT HERE]

Students responded twice (April 1991, January 1992) to the following set of statements (source of statement in parentheses) by indicating their degree of agreement from three options ("agree," "disagree," and "other"). During the junior year, students supported each response in three to five-sentence paragraphs; during the senior year, they wrote a four to seven-page essay in which they supported their answers.

- Scientific knowledge is artificial and does not show nature as it really is. (Gilbert, 1991)
- Scientific knowledge more and more approximates truth. (Lakoff & Johnson, 1980)

- Scientific laws and theories exist independent of human existence. Scientists merely discover them. (Lakoff & Johnson, 1980)
- Science, like art, religion, commerce, warfare, and even sleep, is based on presuppositions. (Bateson, 1980)
- The social environment of a scientist will not influence the content of the knowledge he or she proposes. (Gilbert, 1991)

During both years, students also wrote four to seven-page essays on the topic of "Knowing and learning physics" in which they were instructed to "address the question of how we know and how we learn with a particular application to our subject, physics. You should ask yourself, <u>but not limit yourself to</u>, questions of the following nature." Some of the suggested questions were, "How do I know physics?," "How do I learn physics?," "Is the knowledge I learn in the laboratory different from the one I learn out of the text book?," and "How does working in a group help me to learn physics?" After completion of the two textbook units on the particle-wave dualism of matter and electromagnetic radiation, students wrote a reflective essay. Here they were to address the implications of the particle-wave dualism for the nature of scientific knowledge in the light of their readings and discussions of "Inventing Reality" and "Fundamentals of Physics."

Every two to three weeks, students read two or three chapters in "Inventing Reality" (Chapters 9 through 12 were omitted because of their difficulty and because of time constraints). Students reacted to the readings in unstructured essays from two to six typed pages in length. Each reading and essay assignment was followed by a teacher-moderated whole-class discussion in which students talked about their understanding of issues related to the readings. All 10 discussions (2 sections x 5 discussions) were recorded and transcribed.

During both years, the preferred form of the Constructivist Learning Environment Scale (CLES) was administered; here, students rated statements about learning environments consistent with a constructivist epistemology (Taylor & Fraser, 1991). CLES is constituted by four groups of seven items, related to <u>autonomy</u>, <u>prior knowledge</u>, <u>negotiation</u>, and <u>teacher expectations</u> (which was considered a better name than the original studentcenteredness [Roth & Bowen, 1995]). Autonomy items make statements about the control of learning activities ("In this class, I decide how much time to spend on an activity"); prior knowledge items address meaningful knowledge integration ("In this class, I think about interesting real life problems"); negotiation items describe opportunities to interact, negotiate meaning and build consensus ("In this class, I talk with other students about the most sensible way of solving problems"); and teacher expectation items describe learning as a process of creating and resolving personally problematic experiences ("In this class, the teacher expects me to remember things I learned in past lessons"). Alpha reliabilities for these subscales were between .75 and .85 which are of the same order as those reported by Taylor and Fraser (1991). We used individual students' answers to the CLES as starting points in the interviews and to provide an indication of their acceptance of the constructivist learning environment which prevailed in the classroom.

Interviews constituted another source of data. During the first year, students were interviewed to clarify written answers to the five questions and points raised in the essays on knowing and learning physics, and to follow up on students' answers to the CLES. After interviewing 11 students, we felt that information was largely redundant and terminated the interview process (Lincoln & Guba, 1985); that is, the group of 11 students constituted a sample of maximum variation in views about the nature of knowledge. Only 3 of these 11 students continued to study senior-level physics.

During the second year, all 23 students were interviewed at least once; three students were interviewed twice to follow up on religious and ethical dimensions in students' discourse. Each 25 to 45-minute interview was kept flexible, but we asked students to talk more about the five statements (to which they had reacted earlier in writing), contents of their essays, and CLES items. We also attempted to elicit students’ reactions to seemingly contradictory statements in their previous written or oral discourse and to elicit further talk about the nature of knowledge and truth. All interviews were recorded and transcribed.

Finally, the data included Roth's reflective notes, type-written comments to students' assignments (laboratory reports and essays), a curriculum guide (which teachers were required to write themselves), and students' grades over the two years. The entire data corpus for the 23 students consisted of more than 2000 type-written pages of essays (ten or more samples per student) and transcripts of interviews and class discussions. The data on the 46 students during the first year of the study had been previously analyzed from a different philosophical and analytical perspective (Roth & Roychoudhury, 1993, 1994). A case study of students' religious and scientific discourses, co-authored by one of the two students will be reported separately (Roth & Alexander, in press). A detailed case study of the interaction between students' discourses about epistemology and their own learning complements the present analysis (Lucas & Roth, 1996).

Data Analysis

We began our analysis of the entire data base by engaging in cycles constituted by independent analysis of part of the data, followed by meetings in which we compared and negotiated emerging constructions, and discussed new directions for the analysis. Lincoln and Guba (1985) discussed this as the "stepwise replication" approach to establish dependability, the qualitative researcher's equivalent to reliability. For example, we had decided to identify students' discursive resources (interpretive repertoires) which they used to support claims about truth and the nature of scientific knowledge. We began each subsequent meeting by comparing our respective lists and supportive examples. For instance, one of us had constructed a category that he labeled "intuitions"; the other had identified a repertoire tentatively labeled "commonsense or mundane resource." By drawing on examples from the data we realized that through our independent ordering processes we had constructed a common category. In other cases, we had attributed technology-related talk across other categories. Differences were negotiated until we found enough common ground to allow us to proceed. That we could arrive at a common set of categories despite our different background assumptions supports the viability of, and lends credibility to, our analyses.

Following recent developments in discourse analysis in education (Lemke, 1990), social and discursive psychology, (Edwards & Potter, 1992), ethnomethodology (Lynch & Bogen, 1996), and science studies (Gilbert & Mulkay, 1984), we were not simply interested in the statements students made about various topics, here truth and the nature of scientific knowledge. Rather, the discursive resources students drew on to support their claims about the topics constituted a central phenomenon of our analysis. Given that students read, wrote about, and discussed a book about the nature of scientific knowledge, we were particularly interested to see if we could observe changes in students' discourse both in terms of the claims and interpretive repertoires displayed.

NOTES

[1] All excerpts from the data are coded according to author (student's name) and/or context ("S1.4" = discussion 4 in section 1; "C2" = chapter essay 2; "FB1" = feedback to chapter essay 1; Essays in which students responded to 5 questions ["5Q"],wrote about knowing and learning physics ["KL"] and the nature of light ["NL"]), and date the document was written, recorded, or submitted (yymmdd). Thus, "Kyle 5Q.910415" refers to Kyle's essay in which he responded to the 5 questions, submitted on April 15, 1991. All student names in this study are pseudonyms.