Undergraduate Science Students' Images of Science

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Abstract: This article describes views about the nature of science held by a small sample of science students in their final year at the university. In a longitudinal interview study, 11 students were asked questions about the nature of science during the time they were involved in project work. Statements about the nature of science were characterized and coded using a framework drawing on aspects of the epistemology and sociology of science. The framework in this study has three distinct areas: the relationship between data and knowledge claims, the nature of lines of scientific enquiry, and science as a social activity. The students in our sample tended to see knowledge claims as resting solely on empirical grounds, although some students mentioned social factors as also being important. Many of the students showed significant development in their understanding of how lines of scientific enquiry are influenced by theoretical developments within a discipline, over the 5–8 month period of their project work. Issues relating to scientists working as a community were underrepresented in the students' discussions about science. Individual students drew upon a range of views about the nature of science, depending on the scientific context being discussed. © 1999 John Wiley & Sons, Inc. J Res Sci Teach 36: 201–219, 1999

Coming to understand science involves gaining insights into a number of facets of science. There is knowledge of the contents and methods of science—that is, the laws, models, theories, concepts, ideas, experimental techniques, and procedures used by scientists. Such *knowledge in science* forms the basis of undergraduate science curricula. There is also knowledge about how scientists develop and use scientific knowledge: how they decide which questions to investigate, how they collect and interpret scientific data, and how they decide whether to believe findings published in research journals. This is *knowledge about the nature of science.* Here, we report students' views about the nature of science; their images of science. We present details of the images of science held by a small sample of undergraduate[1] science students.

For students, the world of professional science is largely outside their everyday experience. Moscovici (1984a) considered people's understandings of unfamiliar, specialized areas of knowledge (e.g., psychoanalysis, computers, or science). We believe that his theory of social

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representations provides insights into the ways in which people come to understand the nature of science. Central to the concept of representations is a distinction between the specialized area of knowledge itself and people's representations of it. Representations are the collections of concepts, ideas, values, and commitments which enable people to think about an unfamiliar issue and allow communication about it within a community. In many cases, representations include tacit understandings which are rarely made explicit. Nevertheless, representations are the "governing principles of our actions," informing the attitudes and activities of individuals and groups (Moscovici, 1993, p. 366). Representations are social in two senses. First, representations are shared and deployed within communities of people; they are "embedded in a collective memory" (Moscovici, 1993, p. 365). Second, representations are constructed, maintained, and changed through social processes:

> The word "social" was meant to indicate that representations are the outcome of an unceasing babble and a permanent dialogue between individuals, a dialogue that is both internal and external, during which individual representations are echoed and complemented. (Moscovici, 1984b, p. 951)

Thus, representations are developed through individuals questioning and interpreting information for themselves (internal dialogue) and through discussions with other members of the community (external dialogue). One of the purposes of this dialogue is to *anchor* aspects of an unfamiliar area of knowledge to a context which is familiar to the individual or community (Moscovici, 1984a). In this way, the common experiences and language of the community influence the construction of representations of unfamiliar areas of knowledge.

The images of science investigated in this study are social representations of the nature of science held by a small sample of undergraduate science students. These students will have had a wide range of exposure to science including school science, science documentaries on television, scientific issues reported in the news, undergraduate science education, and interactions with science teachers. These experiences of science give students episodic knowledge about science—knowledge focused on particularly memorable events or anecdotes involving science. From the perspective of social representation theory, these episodic experiences of the unfamiliar and specialized world of science will form the basis of internal and external dialogue about science through which images of science are constructed, sustained, and changed. This dialogue includes students asking themselves questions about science (internal dialogue), and also external dialogue involving discussions amongst nonscientists and discussions with individuals who have a privileged access to science (e.g., research scientists and science teachers). In this way, we can expect students' images of science to be most effectively developed through involvement in discourse communities in which scientific ideas and perspectives are routinely discussed and within which internal and external dialogue about the nature of science occur regularly and spontaneously.

Images of science provide reference points which enable the student to act within a scientific environment. Students will draw on these images in talking about science and in deciding on appropriate courses of action during scientific tasks. Thus, whereas images of science are seen as generated and continually developed through social interaction, they also have a significant effect on an individual's personal action, talk, and thoughts about science.

Significance of Students' Images of Science

Studies have been undertaken of school students' images of science and the significance of these findings for teaching and learning science in schools (Carey, Evans, Honda, Jay, & Unger, 1989; Driver, Leach, Millar, & Scott, 1996; Lederman, 1992). Attention has also been given to the images of science held by the population in general (Durant, 1990; Miller, 1983). For undergraduate science students, we see two reasons why the development of images of science is particularly important. First, there is growing evidence that students' actions during science-learning tasks are influenced by their ideas about the nature of scientific knowledge (e.g., Edmundson & Novak, 1993; Lucas & Roth, 1996; Shapiro, 1989; Songer & Linn, 1991). Second, science graduates become journalists, teachers, business-people, civil servants, or politicians, as well as professional scientists. These science graduates may need to carry out tasks which require an understanding of the nature of science: for example, teachers describing the activities of science to students, and health officials informing the public on scientific evidence relating to food safety. Depending on the task, some images of science may prove problematic. For example, teachers who believe that scientific truths emerge unproblematically from experimental data may expect their students to discover scientific ideas during school laboratory work (Brickhouse, 1990).

In a study of images of science held by a small sample of undergraduate students, we set out to address the following research questions:

1. What range of images of science do undergraduate science students hold?
2. Do students' images of science change as a result of undergraduate curriculum experiences?

The interaction between these students' images of science and their experiences of the undergraduate course is reported elsewhere (Ryder, Leach, & Driver, 1997).

Methodology

Discussions about the nature of science among philosophers, historians, sociologists, and scientists have shown that there is no single view of science which can be used to interpret the diversity of scientific activities. Indeed, there is often disagreement among these scholars over the interpretation of specific scientific events. Details of the nature of science depend on the discipline (e.g., condensed matter physics, paleontology) and the purposes of the activity (e.g., producing a product, developing a theory). Furthermore, as discussed earlier, students' images of science are constructed informally from a wide range of experiences of science. These images of science will have been assembled without conscious attempt to construct a systematic image of science to be deployed in all contexts. As a result, individual students have a profile of images of science. A student exhibiting a particular image of science in one context may deploy a different image of science in another. The breadth of the profile reflects the number of different images of science available to the student. Mortimer (1995) showed that this range of images of science is reflected in each student's profile of understandings in specific concept areas.

The notion of a profile of images of science suggests that studies need to explore the range of images of science which individual students draw upon in given situations. For example, when discussing physicists' attempts to establish an accurate value for the gravitational constant in Newton's universal law of gravitation, an individual student may emphasize the importance of a systematic and methodical approach to data collection and interpretation. However, the same student talking about physicists' attempts to unravel the subatomic structure of matter may emphasize the importance of highly creative and unorthodox approaches to data collection and interpretation. To probe students' images of science profiles, our study was set within a teaching activity which would allow discussion about science within a variety of specific scientific contexts. Such a methodology contrasts with that followed by those who have tried to characterize individual students' images of science against a set of normative frameworks, such as whether the respondent's perspective reflects the views of either T.S. Kuhn or Karl Popper (Rowell & Cawthron, 1982).

We chose to investigate the images of science held by students working on final-year undergraduate research projects. At the University of Leeds, these research projects take up to 8 months to complete and involve the student working alone under the supervision of a science lecturer, possibly within a professional research laboratory. Many of the projects involve original scientific research. Indeed, for many students, it is the first time they are investigating a problem to which nobody else has an answer. As a result, students are likely to be drawing upon and developing social representations about the nature of science with a particular emphasis on the day-to-day working practices of research scientists.

Although pencil and paper surveys of undergraduate students' images of science have been conducted (Bell & Lederman, 1996; Fleming, 1988: Rowell & Cawthron, 1982), we felt that an interview-based case study approach was most suited to building up a picture of the range of images of science drawn upon by an individual student in response to a variety of contexts. Interviews allow the researcher to establish the contexts which students call to mind when responding to open questions about the nature of science, and to clarify the precise meaning of words used by the respondent, such as "experiment," "theory," "prove," or "hypothesis" (Lederman & O'Malley, 1990).

A sample of 11 students of different levels of attainment, gender, and project type was selected from four science departments at the University of Leeds. Table 1 gives details of the sample. No attempt was made to generate a sample representative of the student population as a whole. Rather, our aim was to investigate the breadth and diversity of individual students' images of science.

The study reported here was part of a larger study into students' experiences of undergraduate science research project work, in which each student was individually interviewed three times (Leach, Ryder, & Driver, 1996). Discussions about the nature of science were included in only the first and third interviews. In each of these interviews, the following stimulus questions were used:

1. How do scientists decide which questions to investigate?
2. Why do scientists do experiments?

Table 1
Details of the student sample

Student	Gender	Department	Project type
A	f	Chemistry	Laboratory investigation
B	m	Chemistry	Computer modeling
C	f	Biochemistry	Laboratory investigation
D	m	Biochemistry	Laboratory investigation
E	f	Biochemistry	Laboratory investigation
F	f	Earth sciences	Database analysis
G	m	Earth sciences	Computer modeling
I	f	Genetics	Laboratory investigation
J	f	Genetics	Laboratory investigation
K	f	Genetics	Database analysis
L	m	Earth sciences	Fieldwork

3. How can good scientific work be distinguished from bad scientific work?
4. Why do you think that some scientific work stands the test of time whereas other scientific work is forgotten?
5. How are conflicts of ideas resolved in the scientific community?

The five stimulus questions were chosen to raise a range of issues about the nature of science which had been identified as important in a previous study (Driver et al., 1996). We also anticipated that questions about why scientists do experiments, how good science can be distinguished from bad science, and how conflicts are resolved would be particularly pertinent for students engaged in project work.

The stimulus questions were asked without reference to any particular scientific context. However, during piloting we found that students responded to questions posed in an open context (e.g., why do scientists do experiments?) by drawing upon an inner context (e.g., specific experiences on their project or stories about science presented in the media). This inner context will not necessarily be mentioned explicitly in the student's response. One of the purposes of the interviews was to encourage students to make explicit the scientific contexts they had in mind during conversations about the nature of science.

Whereas there have been studies of the development of school students' images of science using longitudinal data (Carey et al., 1989; Roth & Lucas, 1997), there appear to be few examples of such work with undergraduate students. In our study, discussions about the five questions above were held in the first and the final interview with students (typically 5 months apart), and students were encouraged to identify any changes in their images of science, including possible influences from their project and elsewhere.

Piloting with two students from the study showed that the questions were effective in encouraging students to talk at length about science. Our aim during the interviews was to get students to talk about science in their own terms. Our approach follows the traditions of phenomenography, in which the focus of research is taken to be descriptions of people's conceptions of the world (categories of description) rather than descriptions of the world itself (Fetterman, 1988: Marton, 1981). Thus, we focus on students' ideas about the nature of science, rather than a description of the nature of science per se.

What Students Say about Science: Limitations of Interview Data

During the interviews, students are trying to make aspects of their images of science explicit. Such espoused views will be subject to the difficulties of effective articulation by the student. This is particularly the case since students' images of science involve tacit knowledge—which is rarely made explicit but which nevertheless informs action (Polanyi, 1967). As a result, we cannot assume that in action situations students only have access to those images of science which they can convincingly articulate during an interview.

Students had widely different experiences during their project work. We can expect these experiences to be reflected in each student's responses to the five stimulus questions. For example, project work by students in the life sciences tended to focus on experimental procedures and protocols, rather than the evaluation of new models or theoretical explanations. This tended to be reflected in these students' discussions about science. However, this does not necessarily mean that these life sciences students are unaware of the model-like nature of much scientific knowledge, but that these issues were not highlighted as part of their project work, and therefore that their project did not provide a ready context for exemplifying such views.

Characterizing Students' Discussions about the Nature of Science

This section describes students' responses in detail. In addition to quotes from our conversations with students, we present a framework which highlights the most recurrent features in students' discussions about science with us.

Method of Analysis

All of the students' responses were analyzed for each question in turn. Categories of response were identified and tabulated. For example, Tables 2 and 3 show the categories of response identified for two of the questions. These tables give the number of students who made a statement of each type, in the first and final round of interviews. Further details are given in Leach et al. (1997).

As a result of this question-by-question analysis, it became clear that certain epistemological and sociological positions recurred among these categories of response. For example, the concept of a scientific research program appears in the students' responses to both of the questions in Tables 2 and 3: research programs as guiding the questions it is legitimate to ask (extending knowledge in Table 2) and research programs as criteria for the longevity of scientific work (coherent field in Table 3). A second phase of analysis therefore attempted to develop a framework which would characterize these fundamental issues running through our conversations with students. Considering the interview transcripts as a whole, each of the authors identified those parts of the students' transcripts which represented coherent statements about science and generated a framework which characterized these issues. We then met to discuss these frameworks and agree on a final framework. This framework will inevitably be colored by our own theoretical insights and interests, and the issues raised spontaneously by students in the context of their project work. Despite these limitations, the framework does give a description of how the students in our sample talked about science during the interviews. The framework

Table 2
Categories of response for Question 1: "How do scientists decide which questions to investigate?"

Category of response	No. of students making statement of each type ($N = 11$): First interview	Final interview
Curiousity led Scientists choose to investigate questions which they are personally curious about.	5	5
Extending knowledge Scientists seek to increase and improve upon the knowledge of the discipline.	3	8
Utilitarian Scientists work to help solve medical or environmental problems, for the benefit of humanity.	5	6
Financial benefit Scientists work in areas for which they know that they can get funding, or which may lead to financial rewards.	6	6
Total	19	25

Table 3
Categories of response for Question 4: "Why do you think that some scientific work stands the test of time whereas other scientific work is forgotten?"

Category of response	No. of students making statement of each type (N = 11)	
	First interview	Final interview
Revolutionary If the scientific work solves a longstanding problem in a revolutionary way, then it will last.	3	3
Coherent field If the scientific work builds on previous work and is consistent with it, then it will last.	3	8
Inherent quality of work If the scientific ideas rest on highly reproducible data, then it will last.	2	2
Utilitarian If the work has many practical benefits to humanity, then it will last.	2	0
Untestable If predictions from the scientific idea are difficult to test, then the idea may last a long time.	1	1
Total	11	14

and associated coding also helped to identify those aspects of the students' images of science which were developed between the first and final interviews.

Characterization of Students' Images of Science

The final framework features three aspects of the nature of science. Section A of the framework, the relationship between scientific knowledge claims and data, is strongly epistemological, representing students' discussions of how knowledge claims arise from and interact with experimental and observational data. Section B, the nature of lines of scientific enquiry, focuses on the extent to which scientists are seen as following a coherent line of scientific enquiry, either individually or as a community. Section C, the social dimension of science, captures students' discussions about science as a collaborative and institutionally regulated activity.

Tables 4–6 give the categories of description for each of Sections A, B, and C, and the results of our coding of the students' discussions within this framework. The numbers in the tables refer to the number of students making statements of each kind, rather than the number of times they were raised in the interviews as a whole. In some cases, students made statements without elaboration. For example, statements that knowledge claims are provable in principle but without an elaboration of the grounds for proof are coded as Ab(o). The final column gives the number of students making statements coded within the main coding categories either in the first or final interviews. Although the total number of students is 11, most students made statements of more than one kind in each section of the framework.

Table 4
Students' views about the relationship between scientific knowledge claims and data

	Category of description for Section A of framework: Relationship between scientific knowledge claims and data.	No. of students making statement of each type ($N = 11$)		
		First interview	Final interview	Total
Aa	**Knowledge claims as description**	**2**	**0**	**2**
Ab	**Knowledge claims as provable**			**11**
Ab(o)	General statement. No elaboration given.	3	1	
Ab(i)	On empirical grounds. No elaboration given.	6	10	
	a. Mention of meticulous procedures for ensuring reliability/validity	4	5	
	b. Mention of "critical expeirments"	3	5	
Ab(ii)	On social grounds	3	3	
Ab(iii)	Recognition of difficulty of absolute proof in practice	5	2	
Ac	**Knowledge claims go beyond the data**			**4**
Ac(o)	General statement. No elaboration given.	4	3	
Ac(i)	Empirical processes involved in evaluating knowledge claims	3	4	
Ac(ii)	Social processes involved in evaluating knowledge claims	2	2	
Ac(iii)	There is no obvious basis for evaluating competing knowledge claims.	0	0	

Note. The final column (Total) refers to the number of students making statements coded within the main coding categories either in the first or final interviews.

In the remainder of this section, we exemplify each of the categories using quotes from our conversations with students. Many students struggled to articulate their views about science. In categorizing students' positions, it was often necessary to consider extended pieces of dialogue during which the student repeatedly indicated a specific image of science. In exemplifying the categories below, we have used short, crisp quotes wherever possible. However, in some cases the short quotes presented here do not in themselves communicate the student's position. In these cases, we have tried to give details of the conversation from which the quote is taken.

Relationship between Scientific Knowledge Claims and Data. Table 4 shows that responses reflected three main epistemological positions concerning the status of scientific knowledge claims: knowledge claims as description, knowledge claims as distinct from data yet provable, and knowledge claims as going beyond the data. Any of these positions may be appropriate depending on the type of knowledge claim being discussed.

The first category represents those statements in which students made no distinction between data and knowledge claims arising from these data (Category Aa). Here, the end point of scientific investigation is seen as generating reliable data, which serves to explain phenomena. Whereas such a view has been identified as significant amongst school children (Driver et al., 1996) only two of the students in our sample made statements of this kind, and these were made in the initial and not the final interview. For one of these students, it was clear that such a position was entirely inappropriate within the project work context under discussion.

Most of the statements made by students involved knowledge claims being recognised as separate from data and provable (Category Ab). Three subcategories relating to the nature of

Table 5
Students' views about the nature of lines of scientific enquiry

	Category of description for Section B of framework: Nature of lines of scientific enquiry	No. of students making statement of each type ($N = 11$)		
		First interview	Final interview	Total
Ba	**Location in individual interests of scientists**	**4**	**9**	**10**
Bb	**Internal location in epistemology of discipline**	**5**	**10**	**10**
Bc	**External location**			**4**
Bc(o)	General statement. No elaboration given.	1	0	
Bc(i)	Utilitarian: for the greater good.	4	3	
Bc(ii)	Financial: in terms of financial viability	7	7	

Note. The final column (Total) refers to the number of students making statements coded within the main coding categories either in the first or final interviews.

proof were apparent. The most common was that knowledge claims are validated on empirical grounds (Ab–i). In addition, some responses, referred to social grounds for the acceptance of knowledge claims (Ab–ii), and some to the difficulty in practice of achieving absolute proof, although this was seen as possible in principle (Ab–iii).

The following response to the final interview question gives an example of a student referring to empirical grounds for proof.

> Interviewer: How are conflicts of ideas in science resolved?
>
> Student: How they resolve them in science is by carrying out experiments that prove one theory is right, proving without a shadow of doubt that theory is the correct one [. . .] A lot of people have two different theories and they do experiments to try and prove those theories and it will be only the one who eventually gets the right experiment at the right time and the theory is proved. (3.D.45–47)[2]

Table 6
Students' views about the social dimension of science

	Category of description for Section C of framework: Social dimension of science	No. of students making statement of each type ($N = 11$)		
		First interview	Final interview	Total
Ca	**Individualist view**	**1**	**0**	**1**
Cb	**Recognition of community of scientists**	**6**	**7**	**8**
Cc	**Recognition of institutions of science**			**7**
Cc(o)	General statement. No elaboration given.	0	0	
Cc(i)	Financial interests recognized.	2	0	
Cc(ii)	Role recognized in validation of public knowledge	4	2	
Cc(iii)	Named institutions or processes recognized	0	1	

Note. The final column (Total) refers to the number of students making statements coded within the main coding categories either in the first or final interviews.

Within this category, students often mentioned the importance of a meticulous approach to experimental procedure or the importance of critical experiments to distinguish between competing theories.

In addition to describing the importance of empirical findings, some students also talked about the influence of social issues on whether a knowledge claim is accepted as proven.

> Interviewer: Supposing two scientists disagree about what a set of results means [. . .] How are those conflicts resolved?
>
> Student: It is to do with what the general opinion is at the time and what other people think. (3.K.36)

Although this student did recognize the importance of empirical data elsewhere in the interview, her response to this stimulus question focused immediately and directly on the opinion of scientists rather than the quality of the results. Other social issues which students mentioned as being important were the personality and status of the scientist who generated the results, the credibility of the scientist based on his or her previous work and personal commitments scientists might have to particular theories. Such statements are represented as indicating social grounds for belief in knowledge claims as proven (Category Ab–ii).

Other statements recognized that whereas knowledge claims can be proven in principle, this may often be difficult in practice (Category Ab–iii). The following statement gives an indication of such a position.

> Evidence could aim at supporting the theory but only by a sideways route. The theory itself, at the end of the day, may not be correct although the evidence supported it. (1.C.120)

Statements in the second main category suggest that knowledge claims are distinct from data yet provable; however, the third category (knowledge claims go beyond the data) identifies proof as problematic in principle. Although some students did articulate views in this area, these views were often expressed obliquely and with difficulty. Students occasionally hinted at the kinds of things that are used to evaluate (rather than prove) knowledge claims (e.g., predictive power of the knowledge claim, its explanatory power, its simplicity and elegance, and its coherence with other knowledge claims in the field).

Statements about knowledge claims as going beyond the data, as for the previous subcategory, are characterized as being based on empirical evidence (Ac–i) and social grounds (Ac–ii). For consistency, we have included the subcategory “no obvious basis for evaluating competing knowledge claims” (Ac–iii), although no students in our sample made statements of this kind.

The following exchange suggests that the student believes a single data set may be explained legitimately by more than one knowledge claim.

> Interviewer: I wonder how you feel that conflicts of ideas are resolved in the scientific community?
>
> Student: Well, it’s often that at least two or three theories will always be there to explain a phenomenon, until maybe it’s proved experimentally. But even then people can change around their theory [. . .] you can have a number of separate theories and then it [is] just fitting to the data, disprove one of them, or leave the two running along side [each other]. (3.G.61)

This student is articulating a sophisticated position in recognizing the possibility of a plurality of theories. Although the point is made rather indirectly in this extract, examination of this student’s transcript as a whole indicates that the student feels knowledge claims can go beyond data (Category Ac), and as a result it is often acceptable to use two or more theories to account for a data set.

Nature of Lines of Scientific Enquiry. The nature of scientific lines of enquiry includes issues such as where scientific questions come from and how lines of work are continued or not. The way students characterized the nature of scientific lines of enquiry was a dominant feature of their conversations with us. It was also an aspect of students' thinking which appeared to be modified as a result of project work. Three categories of description were identifiable as shown in Table 5: individual interests of scientists, internal epistemology of the discipline, and external location (e.g., financial, utilitarian).

Much of the discussion about the nature of lines of enquiry occurred in response to the first stimulus question.

> Interviewer: How do scientists decide which questions to investigate?
> Student: I think a lot depends on that person's particular interest and what that particular person might perceive will be beneficial to mankind or will be of any use to the human race in general. I think that's what makes them decide [. . .] and obviously the case of funding. If they get funding for it. (1.J.48)

This student mentions the significance of a scientist's personal curiosity (Category Ba) and the influence of external factors such as the desire to benefit humanity and the desire to get funding (Categories Bc–i and Bc–ii). For some students, the influence of the desire to benefit humanity (a utilitarian view) was particularly strong, and appeared throughout their discussions about science.

Students also made references to influences on the direction of enquiry from within science.

> Interviewer: How do you think scientists decide which questions to investigate?
> Student: [. . .] Commercial interest, I suppose, where there's money involved, certain people want things finding out. And I suppose areas where a lot of research is going on that lend themselves to a lot of questions would come up there, sort of topical areas.
> Interviewer: So there's the commercial interest and the topicality aspect. Where does this topicality come from? Tell me what your idea of that is.
> Student: Well, for example, in geology the plate tectonics theory which has come about since the 1960s has provided most of the questions that people are trying to answer at the moment in research. So things like that. Theories which suddenly come to light would really need a lot of investigation. (3.F.48–49)

Such statements reflect the view that lines of enquiry are influenced by the theoretical ideas of the discipline (category Bb). We have characterized this position as recognizing the importance of the internal epistemology of the discipline: that the major ideas and theories of the discipline have a major influence on the questions which scientists set out to answer.

Social Dimension of Science. Discussions in this category focused on the role of social processes in determining the direction of scientific enquiries, and the existence and function of the institutions of science. We found that these discussions could be resolved into three main categories (Table 6). The individualist view describes scientists as working entirely alone, without interaction with other scientists (Category Ca). Other statements recognized the existence of a community of scientists who interact, although few students elaborated on why this might be necessary or useful (Category Cb). The importance of the institutions of science in regulating and directing the funding of scientific work and in validating new knowledge claims (Categories Cc) has been recognized as an important aspect of the social dimension of science (Kuhn, 1970; Ziman, 1995). This includes the role these institutions have in influencing the direction of scientific enquiry and the validation of knowledge claims through processes such as peer review.

The following response to the question, "Why do you think that some scientific ideas stand the test of time whereas other scientific ideas are forgotten?" is an example of one student elaborating on the ways in which scientific work requires interaction amongst scientists (Category Cb).

> I guess the history of science, basically someone comes up with an idea and everybody clambers to debunk it and come up with a fresh idea, continuing on from that and making some alterations. So that the person who immediately came up with the idea his name is kind of forgotten and the next person gets a bit of acclaim for it. And then someone who stood the test of time would have a theory that's a bit more difficult to pull apart by the other scientists. (3.L.43)

This student believes that the existence of a community of scientists is necessary to maintain a critical control on the validation of new knowledge claims.

Using the Framework to Describe Images of Science Held by Students in Our Sample

In this section, we use Tables 4–6 to consider whether these students' images of science develop as a result of undergraduate curriculum experiences.

Relationship between Knowledge Claims and Data

Table 4 shows that all 11 students in our sample made statements indicating that knowledge claims could be proved absolutely. Of these statements, the majority focused on empirical data as the sole grounds for proof. This finding supports that of Rowell and Cawthron (1982), who reported that university students tend to advance a Popperian view in which scientific ideas are either accepted or falsified on the basis of empirical data. This contrasts with a Kuhnian view in which social processes, in addition to empirical processes, are considered influential in the progress of science.

Four students also made statements that knowledge claims go beyond the data, and therefore that proof is problematic. Those students making the strongest statements of this kind were students from the Department of Earth Sciences. This suggests that subject discipline is an important influence on the statements students make about science. It is significant that all of these students also made statements indicating that knowledge claims are provable in principle. This might suggest that students are contradicting themselves. However, closer examination of those cases in which students are able to elaborate their reasoning clearly suggests that the different views arise from a consideration of knowledge claims from different science contexts. As discussed earlier, this indicates that students possess a profile of images of science rather than a single coherent view which they apply in all contexts.

Was there evidence of developments in individual students' profiles as a result of their project work? Table 4 gives our findings for the student sample as a whole. To show whether individual student's developed their views between the first and final interviews, we use transition

		Final Interview	
		No statements	Statements made
First Interview	No statements	0	4
	Statements made	1	6

Figure 1. Transition matrix for all categories of knowledge claims as provable on empirical grounds (Categories Ab–i).

matrices such as Figures 1 and 2. These matrices indicate the numbers of individual students who made statements of a given category (or set of categories) in both interviews, the first or final interviews only, or neither of the interviews. Figures 1 and 2 give transition matrices for those categories toward which the students in our sample made the biggest shift in the final interview. For example, Figure 1 shows that of the four students who made no statement within categories Ab(i) in the first interview, all four made such a statement in the final interview. Of the seven students who did make such a statement in the first interview, six repeated this view in the final interview. Thus, Figure 1 shows a noticeable shift at the individual level.

The transition matrix in Figure 1 represents the changes individual students showed for all of the possible statements in the category "knowledge claims as provable on empirical grounds." As outlined above, Figure 1 shows that four students made statements about empirical proof in the third interview which were not present in their first interview. Evidence for an increase in statements about empirical proof also comes from the codings used for each of the stimulus questions. For example, in response to the question, "How can good scientific work be distinguished from bad scientific work?" many more students made statements about the importance of a "critical approach to experimentation" in the third interview (Leach et al., 1997, p. 31). This increasing emphasis on the quality of data is not surprising given that students' project work often involved repeatedly working to get reliable experimental data.

		Final Interview	
		No statements	Statements made
First Interview	No statements	1	5
	Statements made	0	5

Figure 2. Transition matrix for lines of enquiry located in the internal epistemology of the discipline (Category Bb).

Nature of Lines of Scientific Enquiry

Table 5 shows that by the final interview, most students had made statements about lines of scientific enquiry being influenced by individual interests, internal theoretical interests, and external factors. A key feature is the increase in the number of students citing internal theoretical interests (category Bb), as shown by the transition matrix in Figure 2. This shift in students' discussions about science was striking and is also evident in our coding of responses to certain of the stimulus questions. For example, Table 3 shows that many more students in the third interview responded to the question, "Why do you think that some scientific work stands the test of time whereas other scientific work is forgotten?" by referring to the importance of a "coherent development of a field." Exchanges in the interviews indicate that informal discussions with doctoral students and professional scientists, and a reading of research literature as part of the students' project work helped to develop students' awareness of theoretical ideas being an important factor influencing the direction of lines of enquiry.

Table 5 also shows an increase in the number of students citing personal interest (Code Ba) in the final interview. Having worked alongside committed and enthusiastic professional scientists and research students during their project work, students were more likely to mention that lines of enquiry were influenced by personal interests in their final interview. However, further discussion tended to show that more students were aware in their final interview that behind this personal interest was a desire to investigate ongoing questions of the discipline. Thus, we interpret the development shown for this category in Table 5 as a probable reflection of the increase in students' awareness of the internal epistemology of their discipline (Category Bb).

Social Dimension of Science

Table 6 shows that fewer students made statements relating to the social dimension of science despite the fact that they had the opportunity to do so in response to many of the five stimulus questions. Although most students recognized that scientists do not work solely as individuals, few elaborated on the ways in which scientists might interact, the purpose of this interaction, and the role of broader institutions in the development of scientific knowledge.

In summary, the dominant view among the students in our sample was that it is possible to prove the validity of knowledge claims using data alone. The influence of social factors, either on the evaluation of knowledge claims or the direction of scientific enquiry, was underrepresented.

We also identified two main areas of change among the students in our sample. First, students tended to lay more emphasis on the importance of empirical processes in evaluating knowledge claims in the final interview. Second, toward the end of their project work, many more students recognized the influence of the theoretical ideas of the discipline in guiding the questions which scientists set out to answer.

Educational Implications

Science Undergraduates' Images of Science

Students in our sample tended to view knowledge claims in science as provable beyond doubt using empirical data alone. If reflected in the views of the final-year science undergraduate population as a whole, this finding gives particular cause for concern. The professional lives of many undergraduate science students will involve communicating new scientific ideas to those outside of science (e.g., as research scientists, teachers, or journalists). In many cases, these knowledge claims may rest on tentative evidence and be contentious within the scientific community—for example, the effectiveness of homeopathic remedies. More fundamentally, the model-like nature of many knowledge claims in science may preclude in principle their proof using data alone. In their professional lives, many science graduates may need to draw on this aspect of scientific knowledge generation when communicating new scientific findings to those outside of science. This suggests that undergraduate science teaching needs to address and develop students' views about the relationship between knowledge claims and data.

For the students in our study the significance of social processes in science were underrepresented on two fronts: first, in terms of their effect on the validation of knowledge claims; and second, in terms of the effect scientific institutions have on the direction of lines of scientific enquiry. Such a shortfall probably reflects the emphasis of undergraduate courses on "ready-made science" as opposed to "science in the making" (Latour, 1987). As we have seen, even during final-year project work, where in many cases science is being made, the emphasis is on getting reliable data. Students who decide to train to be professional scientists will have further opportunities to develop this area of their images of science profile during their doctoral studies through attendance at conferences, discussions with other scientists, and their own attempts to get their ideas accepted. However, we have emphasized the importance of communicating a realistic image of the social practices of science to those science graduates who will not become professional scientists. For example, depending on their views about the effect of social processes on the validation of knowledge claims, in their professional lives these students may interpret disputes within the scientific community either as suggesting the need for additional data or possibly as unveiling the personal prejudices of particular scientists or groups of scientists. If the sociological shortfall identified in this study is reflected in the student population as a whole, then this suggests that science curricula need to consider the development of students' images of the social processes of science.

Developing Students' Images of Science

Earlier, we identified two key areas of development between the first and final interviews: the role of theory in guiding the questions which scientists investigate and the significance of critical experiments and procedures in the proof of scientific knowledge claims. For some students, these developments were particularly striking and probably reflect an important development of their images of science. This finding, albeit for a very few students, contrasts with that of Fleming (1988), who found using written responses in a pencil and paper survey that there was little if any difference in the images of science held by high school graduates and undergraduate science students. Our own study suggests that given appropriate teaching contexts, students' images of science can be significantly broadened and developed.

In some cases, students made specific reference to incidents within their courses which had developed their ideas about science. For example, discussions with lecturers about incidents from the history of science, such as the work of Watson and Crick in biology, and plate tectonics in geology, were frequently mentioned. In addition, the nature of the student's discipline and the type of project he or she was working on were important influences on the development of the student's images of science. For example, we found that students whose project had an epistemological focus (e.g., relating data to knowledge claims) tended to show developments in their epistemological reasoning. By contrast, students whose projects involved making experimental techniques work with novel materials tended to show limited development in their reasoning about data and knowledge claims.

Influences on students' images of science can be classified as either explicit or implicit curriculum messages (Ryder et al., 1997). Showing students a video about the life of a famous scientist, and using this video to initiate a discussion about the ways in which scientific ideas come to be accepted both within and outside the scientific community, is an example of explicit teaching about the nature of science. Giere (1991) and Matthews (1994) have argued for the promotion of courses in which teaching focuses explicitly on the nature of science. Although such courses may develop students' ideas, there is no guarantee that these ideas will be adopted by students and drawn upon in their other courses or during their professional lives. Furthermore, messages from such courses are inevitably competing with implicit curriculum messages about the nature of science. Implicit messages are communicated continually through the undergraduate course—tutorial discussions, laboratory tasks, lectures, and project work. During interviews, it was clear that those students whose projects had involved working closely with professional scientists and research students had learned a great deal about the world of science, even though such issues were rarely discussed explicitly.

Science Teachers as Mediators of the Nature of Science

For many of the students involved in this study, project work was a socialization into the practice of scientific research in universities (Brown, Collins, & Duguid, 1989). Students got to know professional scientists and research students as colleagues. They were able to express their own ideas and discuss them with experts in the field. They heard stories about the activities of contemporary scientists—both the successes and the failures. They heard about major conflicts of ideas and how they were resolved, and also about scientists who are currently engaged in conflicts of ideas which are yet to be resolved. Students whose project work involved working within an active research laboratory among doctoral students, postdoctoral scientists, and technicians learned about science through a form of apprenticeship. They were able to work alongside professional scientists, learning about the ethics of scientific research, the lifestyle of the science researcher, and the tricks of the trade which enable professional scientists to operate at the frontiers of their discipline. Such students were embedded in a rich community of scientific discourse. In the context of science education as a whole, final-year project work is probably unique in establishing this culturally rich, expert–apprentice teaching context, although Roth (1995) has suggested that such a teaching context can be realized at the high school level.

This emphasis on discussion about science reflects what Moscovici (1984b, p. 951) termed the "unceasing babble" which enables individuals to make sense of the unfamiliar. As a social representation of science, a student's images of science are built up from his or her experiences of science. Working among other scientists and students of science gives the student experiences which prompt discussions about science with others (external dialogue) and encourages the student to make sense of these experiences (internal dialogue). Also, as a social representation of science, students' images of science enable them to communicate about science within a scientific community. They enable students to make sense of their experiences, share their experiences with others, and appreciate the kinds of questions it is meaningful to ask. Finally, experience of a scientific community enables the student to anchor his or her ideas about the unfamiliar world of science in personal experiences of what it is like to be a scientist. Students can contextualize abstract ideas about the nature of science in terms of concrete experiences. Throughout all of this activity, the science teacher's role is that of a mediator between the world of science and student, providing implicit and explicit messages about the nature of science.

Our study has identified the features of a teaching context which has been seen to develop students' images of science. We now draw upon these features to speculate about teaching contexts elsewhere in the undergraduate curriculum which could promote the development of students' images of science. One key feature of final-year project work is the exposure it gives students to a culture of research practice. Other teaching contexts might seek to re-enact specific aspects of the activities of professional scientists. For example, students could be asked to read a number of published research articles and write a review of the ideas contained in them, including their evaluations of any disputed findings or interpretations. Students could also be asked to prepare an account of one of their laboratory investigations for publication in a popular science journal such as *Scientific American* or *New Scientist.* A second key feature of final-year projects is the opportunity they can gave students to articulate, and justify, their images of science. Laboratory work and fieldwork activities can provide contexts in which students can discuss with their peers or with more experienced science students the uncertainties and ambiguities present in measurements, the difficulties of absolute proof, and the conjectural nature of many knowledge claims. Furthermore, tutorial discussions can focus on the ways in which canonical scientific knowledge often emerges after a long period of controversy and dispute among scientists. Throughout these activities, students can be encouraged to voice their own ideas about science. In identifying suitable teaching contexts elsewhere in the undergraduate course, the framework of images of science presented in Tables 4–6 could be used to structure the learning aims of these activities, with a particular focus on those areas of the framework in which students, as least in our sample, have underdeveloped images of science.

As mediators of the cultures of science, science teachers at all levels in the educational system need to make explicit to themselves the images of science communicated through existing curriculum activities and those additional images they wish to incorporate in new curriculum developments. The framework of students' images of science presented here summarizes a range of issues for teachers to consider. The teachers' role is to communicate such ideas either explicitly or implicitly in their teaching. Highlighting the issue of images of science with teachers and students is an important step toward developing an undergraduate curriculum which adequately represents science to students.

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Notes

[1] In the United Kingdom, university science undergraduates specialize in a single science subject for the entire 3–4 years of study. Those students entering the university straight from school will graduate at age 21–22 years.

[2] Quotes are referenced as follows. The first number denotes the first (1) or final (3) interviews. "A–L" refers to individual students. The final number refers to the position in the transcribed interview text.

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