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ABSTRACT

In the United Kingdom, university science undergraduates specialize in a single science subject for the entire 3-4 years of study. This study examines images of the nature of science held by science students in their final year at university. Data are drawn from a longitudinal interview study of 11 students engaged in open-ended project work at the University of Leeds (Leeds, England). Images of science expressed during these interviews are characterized and coded using a framework involving three distinct areas of epistemological and sociological reasoning: (1) the relationship between data and knowledge claims; (2) the nature of lines of scientific inquiry; and (3) science as a community of scientists. Students tended to view knowledge claims as provable solely on empirical grounds, though some students mentioned social factors as also being important. Many students showed significant development in their understanding of how lines of scientific inquiry are influenced by theoretical developments within a discipline. Issues relating to scientists working as a community were underrepresented in the students' discussions about science. Rather than a single image of science, individual students drew upon a range or profile of positions in each area of the framework, depending on the scientific context being discussed. The framework of students' epistemological and sociological reasoning developed here may help to identify areas in existing undergraduate curricula in which students' images of science could be developed. (Author/PVD)

Undergraduate science students' images of the nature of science

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Abstract

This study examines images of the nature of science held by science students in their final year at university. Data is drawn from a longitudinal interview study of eleven students engaged in open-ended project work. Images of science expressed during these interviews are characterised and coded using a framework involving three distinct areas of epistemological and sociological reasoning: the relationship between data and knowledge claims, the nature of lines of scientific enquiry, and science as a community of scientists. Students tended to see knowledge claims as provable solely on empirical grounds, though 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. Issues relating to scientists working as a community were under-represented in the students' discussions about science. Rather than a single image of science individual students drew upon a range or *profile* of positions in each area of the framework, depending on the scientific context being discussed. Finally, it is suggested that the framework of students' epistemological and sociological reasoning developed here may help to identify areas in existing undergraduate curricula where students' images of science could be developed.

1 Bringing undergraduate science students inside of science

Knowledge relating to science may be seen as involving two interrelated areas. Knowledge *of* science involves the laws, models, theories, concepts, ideas, experimental techniques and procedures of science. Such knowledge forms the basis of undergraduate science curricula. However, there is also knowledge which is under the surface of scientific activity and science curricula: knowledge about how scientists decide which questions to investigate, how scientists interpret data they have collected, how scientists decide whether or not to believe findings published in research journals. Such knowledge refers to *the nature of* science. Bringing students inside of science involves introducing students to both areas of knowledge: giving students an appreciation of the ideas which scientists work with and how scientists work with them; helping students to develop a range of mental *images of the nature of science* which can be drawn upon in different contexts.

The significance of an individual's images of the nature of science has been considered for students in compulsory schooling (Driver et al 1996) and the population in general (Durant 1990). For undergraduate science students[1] we can highlight two arguments for the significance of their images of science. From a learning perspective there is evidence that students' approaches to learning tasks are influenced by their images of the nature of the discipline (Edmundson and Novak 1993, Schommer et al 1992, Songer and Linn 1991, Shapiro 1989). For example, Leach et al (1997) describe the case of an undergraduate science student whose discussions about science included the view that the endpoint of experimental investigation was data - scientific knowledge emerged from data without any requirement to work with data using theoretical insights. During her project work this

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

student made little attempt to interpret her own data in terms of scientific theory. It appears that in this case the student's image of the nature of data prevented her from making progress on her project. Cases like this suggest that developing undergraduate science students' images of the nature of science may help students to learn more science from existing teaching contexts.

Looking beyond the science course itself, there is a 'cultural' argument for the significance of science students' images of the nature of science. Science graduates become journalists, teachers, business people, financiers, civil servants, politicians as well as professional scientists. These science graduates will be required to make decisions which require an understanding of the nature of science: scientists giving their critique of a research paper, journalists writing articles about new scientific discoveries, teachers describing the 'process' of science to students, civil servants preparing briefing documents on scientific issues for government ministers, and health officials informing the public on scientific evidence relating to food safety. 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). Inappropriate images of the nature of science carried from undergraduate science courses may have a significant impact on the effectiveness of science graduates in employment.
In a study of undergraduate students' images of the nature of science we set out to address the following research questions:

1. What range of images of science do undergraduate science students use?
2. Are students' approaches to learning science influenced by their images of science?
3. In what ways do curriculum contexts influence students' images of science?

In this paper we focus on the first question, presenting baseline data on the images of the nature of science held by a small sample of undergraduate science students in their final year of study. The interaction between students' images of science and their experiences of the undergraduate course (questions 2 and 3) is reported elsewhere (Leach et al 1997).

2 Investigating undergraduate science students' images of the nature of science

Students have a range of ideas about science. For instance a student's views about how scientists decide which questions to investigate may depend on whether the scientist is involved in university research or research within the laboratories of a multinational pharmaceutical company. Ideas about science depend on the context. In order to provide a context for discussions about science we decided to probe students' ideas about science whilst they were heavily involved on a specific teaching task.

Choosing an appropriate context

We chose to investigate the images of science held by science students working on final year undergraduate research projects. These research projects take up to eight months to complete, and involve the student working alone under the supervision of a science lecturer. Many of the projects involve original scientific research. These research projects are a particularly pertinent teaching context since for many students they represent their first opportunity to 'get inside of science' - experiencing the actual practices of science. As a result their images of the nature of science are likely to be particularly prominent - in terms of being drawn upon and being developed. Furthermore, by focusing on final year students, the images of science we probed would be those carried into the students' graduate careers.

A sample of 11 students showing a range of ability, gender and project type was selected from four science departments at the University of Leeds - Biochemistry & Molecular Biology, Chemistry, Earth Sciences and Genetics. Although broad surveys of undergraduate students images of science have been used (Fleming 1988, Rowell and Cawthron 1982, Bell and Lederman 1996) we felt that a case study approach was needed in order to build up a picture of the *range* of images of science drawn upon by an *individual* student in response to a variety of contexts. Case studies also help us to address our second and third research questions concerning the interaction between images of science and teaching context.

What students say and what students do

Our interest is in the images of science drawn upon by students in specific contexts. These images of science may be transitory and are not articulated by the student at the time. They are 'images in action'. These images of science underpinning what students *do* are not directly accessible to the researcher. In our study we used interviews in which students were encouraged to talk about their images of science with reference to particular activities on their project. These views represent what students *say* about what they do. Such espoused views will be subject to the difficulties of effective recollection and articulation by the student.

Students talking about science

Discussions with students about their images of science formed part of a larger study into students' experiences of undergraduate science research project work (Leach et al 1996). As part of this study each student was interviewed three times. Discussions about the nature of science using the following questions were included in the first and last interview:

1. How do scientists decide which questions to investigate?
2. Why do scientists do experiments?
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 whilst other scientific work is forgotten?
5. How are conflicts of ideas resolved in the scientific community?

These questions were designed to encourage the student to address the following issues: the purposes of scientific work, the nature and status of scientific knowledge and science as a social enterprise (Driver et al 1996). 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 the students to talk about science in their own terms - an ideographic approach. This methodology contrasts with nomothetic studies (e.g. Rowell and Cawthron 1982) which aim to assess students' images of science with reference to particular views of science, e.g. those of Popper and Kuhn.

Whilst there have been studies of the *development* of school students' images of science using longitudinal studies (Carey et al 1989) there appears to be no such work with undergraduate students. In our study, discussions around 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.

3 Characterising students' images of the nature of science

A framework of students' epistemological and sociological reasoning about science

Examination of the students' responses to the five questions showed that discussion centred around epistemological issues (grounds for believing scientific knowledge is true) and sociological issues (the operation of science as a community). These issues tended to run through a student's responses to the questions. Our analysis of the interviews involved designing a coding framework which captured the various forms of epistemological and sociological reasoning which students used. This framework was generated by an iterative procedure. The three researchers involved each identified those parts of the students' transcripts which represented coherent statements about science and then generated a framework which characterised the main modes of reasoning. The researchers then met to discuss these frameworks and to agree on a final framework. This was then used to code the issues raised by each student.

The framework represents our collective interpretation of the students' discussions. One purpose of the framework is to give a description of how the students in our sample talked about science during the interviews. The framework, and associated coding, also helps to identify those areas which were under-represented in students discussions about science. The framework can not claim to adequately represent all issues relating to images of science which may be held by the student population in general. The framework will inevitably be coloured by our own theoretical insights, questions put to students, issues raised spontaneously by students, issues followed up during the interviews, and the emphasis on discussions about science in the context of the students' project work.

The final framework features three main areas of discussion: the relationship between scientific knowledge claims and data; the nature of lines of scientific enquiry; and science as a community of scientists. Figure 1 gives the coding categories and sub-categories for each of these areas. Figures 2, 3 and 4 summarise the issues raised by the eleven students in our sample. Multiple statements referring to a specific code were counted once only for each student. Thus, the graphs represent the range of images of science raised by the students in our sample, rather than the number of times they were raised in the interviews as a whole.

The relationship between scientific knowledge claims and data

Responses suggested three main epistemological positions concerning the nature of knowledge claims (i.e. the theories, laws, hypotheses, models and ideas of science): knowledge claims as description; knowledge claims as distinct from data yet provable; and knowledge claims as going beyond the data.

The first epistemological position represents those statements in which students made no distinction between data and knowledge claims arising from this data (code Aa). Here the endpoint of scientific investigation is seen as reliable data, which serves to explain phenomena. Figure 2 shows that two of the students in our sample made statements of this kind.

Most of the statements made by students involved knowledge claims being recognised as separate from data and provable (code Ab):

> How are conflicts of ideas in science resolved?
>
> *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]

This statement refers to empirical grounds for theory acceptance (code Ab-i). 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.

Empirical data was not the only factor mentioned which influenced whether a knowledge claim could be considered as proven. Consider the following exchanges between interviewer and student:

> Do you agree that there are conflicts of ideas in science?
>
> *I would say so. Definitely. People have their own personal opinion on certain issues.*
>
> How are they resolved?
>
> *Well, you could say by proving something, by experimental proof but even then if someone doesn't want to believe something then they will call into question the experiment and techniques used or [claim] it's a one-off situation. I think if someone doesn't believe something then it's very difficult to prove it to them. If someone's neutral then you can prove that*

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

that is the case (...) but if someone doesn't want to [believe] then it is much more difficult (...) I would say that in their own field most people are quite opinionated. Obviously one scientist can't know the whole area of science but in their own area most people have their own opinions on the major findings.
(3.C.52-53)

Whilst this student recognises the importance of empirical data she also feels that individual scientists are influenced by their own personal perspective in deciding whether or not to accept a knowledge claim as proven. This personal perspective of the scientist can be shaped by many issues including the scientist's theoretical background, and that of the people with whom they work. Such statements are represented as indicating *social grounds* for belief in knowledge claims (code Ab-ii). Other statements recognised that whilst knowledge claims can be proven in principle, this may often be difficult in practice (code Ab-iii).

Figure 2 shows that the majority of students in our sample made statements that knowledge claims could be proven 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 report 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.

A third area of epistemological reasoning was also evident in the students' responses:

I wonder how you feel that conflicts of ideas are resolved in the scientific community?

Well it's often that at least two or three theories will always be there to explain a phenomena, until maybe it's proved experimentally. But even then people can change around their theory (...) that's the thing with (...) geophysics, it's a less exact science than sort of something like physics where eventually you will be able to prove whether someone's completely wrong or right. But with geophysics and geology people seem to be able change around their views a bit to sort of fit the data (..) 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. Though the point is made rather obliquely in this extract, examination of this student's transcript as a whole indicates that they feel knowledge claims can go beyond data (code Ac). For example, in accounting for new experimental data, a theoretical model will draw on ideas which do not emerge from this data, or were even considered as important during the original experimental investigation. To generate a knowledge claim scientists add something extra: creative insights, hunches, inspiration or a strong personal commitment to an idea (Marton et al 1994). Figure 2 shows that a minority of students made such statements. It was striking that the strongest expressions of this type came from students from the Department of Earth Sciences. This suggests that there may be significant disciplinary differences in students' images of the nature of science.

Overall, the discussions of student in our sample emphasised the importance of obtaining reliable, valid data. Indeed this view was strengthened in the third interview after the students had completed their project work. This may not be surprising given that the students' project work often involved repeatedly working to get 'good' experimental data. However, what is missing for many students is any discussion about the nature of data interpretation - particularly the role of conjecture. If undergraduate students are to be brought 'inside of science' this area of epistemological reasoning needs to be appropriately developed.

The nature of lines of scientific enquiry

Students made many statements about the factors which influence scientists' decisions to follow a particular line of enquiry. The following statement is typical:

> How do scientists decide which questions to investigate?
>
> *I think a lot depends on that persons 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 do get funding for it. (1.J.48)*

This student mentions the significance of a scientist's personal curiosity and the influence of external factors such as the desire to benefit mankind and the desire to get funding (codes Ba, Bc-i and Bc-ii). These personal and social factors influencing lines of enquiry contrast with the ideas expressed in the following exchange:

> How do you think scientists decide which questions to investigate?
>
> *(...) 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.*
>
> So there's the commercial interest and the topicality aspect. Where does this topicality come from? Tell me what your idea of that is.
>
> *Well for example in geology the plate tectonics theory which has come about since the 1960's 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 (code Bb). Figure 3 shows that statements of this kind were mentioned by twice as many students in the final interview. Discussions 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, developed students' awareness of theoretical ideas being an important factor influencing the direction of lines of enquiry.

Figure 3 also shows an increase in the number of students citing personal interest (code Ba) in the final interview. Having worked alongside 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, the development shown for this code in figure 3 probably reflects the increase in students' awareness of the internal epistemology of their discipline (code Bb).

Overall, the increasing emphasis on lines of enquiry being influenced by theoretical developments within the discipline was encouraging, and indicates that many of the students in our sample are being brought 'inside of science'. However, solely 'personal interest' and/or 'utilitarian' views of scientific enquiry have persisted for many students in our sample through to the beginning of their final year of study. It seems that project work is a significant and important influence on students' ideas in this area.

Science as a community of scientists

Figure 4 shows that students made few references to scientists working as a community. Whilst only one student referred to scientists as working in isolation (code Ca), few other students developed the idea of how scientists work together in response to the interview questions. Most statements mentioning a community of scientists (code Cb) merely recognised that scientists do interact and discuss their work with each other, without discussion of why this might be necessary or useful. The following statement is an exception:

> Why do you think some scientific work stands the test of time, it just seems to just last and be used for a long time, whereas other scientific work sort of surfaces and then disappears very quickly?
>
> *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 statement reflects the idea that the existence of a community of scientists is necessary if a Popperian cycle of conjecture and refutation is to be sustained. Such a statement recognises the role that the community of scientists has in the validation of scientific knowledge (code Cc-ii).

The institutions of science such as professional science organisations (Institute of Biology, Royal Society), research journals, major science conferences and funding bodies (Wellcome Trust, Research Councils) were rarely mentioned in the interviews (code Cc) - particularly the role these institutions have in influencing the direction of scientific enquiry and the validation of knowledge claims through processes such as peer review (codes Cc-i and Cc-ii). This is perhaps not surprising given that undergraduate students are not expected to attend conferences or make grant applications for research funding. However, from the perspective of the 'cultural' argument presented in section 1, this lack of sociological awareness may handicap those students whose graduate jobs involve interacting with the world of science.

4 Individual student's epistemological and sociological profiles

So far we have concentrated on the epistemological and sociological reasoning exhibited by the 11 students in our sample as a whole. How might the framework in figure 1 look if applied to individual students? Students often expressed several different forms of reasoning for each of the three areas of the framework in the same interview. We believe that the range of reasoning exhibited by individual students reflects the importance of the context in which the student is talking. Consider the following exchange:

> How do scientists decide which questions to investigate?
>
> *I am not really quite sure if I could answer that now actually. I suppose it depends what's the driving force behind the research in the first place. If it's commercially based then they are going to try and look at... I'm not really quite sure to be honest!*
>
> Keep talking though, this is fascinating. You are talking about looking at the underlying basis of the research, can you say a little bit more about that?
>
> *It depends on why the research is being done, if it's for medical reasons or commercially based or some sort of pharmaceutical product research then they have certain goals at the end that they are trying to achieve (...) but the sort of thing I was doing which is not really applied in a sense, it's just on its own merit, it is just scientific research and then I suppose scientists could follow - well they could ask any questions really, if there are no constraints on that lab then they can literally take it anywhere. (3.E.23-24)*

In this extract the student has drawn on two different contexts in her answer: pharmaceutical product research and 'pure' research. This gives two distinct positions about the nature of lines of enquiry: the influence of a scientist's personal interest and the significance of financial reward.

The range of ways in which students are able to think of science represents an individual *profile* of epistemological and sociological reasoning. Depending on the context, the student will draw on different forms of reasoning in their profile. This has an important methodological implication for studies designed to probe students' images of science: it cannot be assumed that students have a single image of science which they apply to all contexts. Rather, studies need to explore the range of images of science which individual students are able to draw upon.

5 Educational implications

The development of a student's epistemological and sociological profile

In section 3 we identified two key areas of development between the first and final interview: the role of theory in guiding lines of enquiry 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 a significant development of their images of science. This finding, albeit for a very few students, contrasts with that of Fleming (1988) who found that 'one could not distinguish the views of a 32 year-old female in her fourth year of university from those of a 19 year-old male in his first year' (page 454).

In some cases students made specific reference to incidents which had developed their ideas about science. For example, discussions about incidents from the history of science and videos about the work of modern scientists. In addition, the nature of the student's discipline, the form of curriculum and teaching they are exposed to and the type of project they are working on, are all potentially important influences on the development of the student's images of science. For example we found that students whose project had an epistemological focus - relating data to knowledge claims - tended to show developments in their epistemological reasoning (section A of the framework). 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.

Many of the influences on students images of science mentioned above can be described as *implicit curriculum messages*. By contrast there has been a move to promote explicit teaching interventions designed to develop students' images of science (Giere 1991, Matthews 1994). Whilst such courses may develop students' ideas there is no guarantee that these ideas will be transferred by the student and drawn upon in their other courses or during their professional lives. Furthermore, the work reported here suggests that messages from such courses are inevitably competing with implicit curriculum messages from traditional teaching contexts.

A sociological shortfall

We have seen that for the 11 students in our sample sociological aspects are under-represented on two fronts: firstly in terms of their impact on the validation of knowledge claims and secondly in terms of the impact scientific institutions have on the direction of lines of scientific enquiry. Such a shortfall reflects the emphasis of undergraduate courses on 'ready made science' as opposed to 'science in the making' (Latour 1987). Even during final year project work, where in many cases science *is* being made, the emphasis is on getting reliable data. Whilst such an emphasis may be understandable, project students rarely develop an awareness that their project is part of a communal research programme which may be guided by a few key individuals: a significant sociological perspective (Ryder et al 1996). 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, the 'cultural' argument put forward at the beginning of this paper emphasised the importance of providing science graduates who will *not* become professional scientists an authentic image of the actual practices of science - bringing them inside of science. Our data shows that many of the students in our sample will carry into their professional lives images of the nature of science which do not fully reflect the actual practices of science.

Using the framework 'both ways' - looking at research and practice

How might the undergraduate curriculum be analysed and developed in order to address issues centred around students' images of the nature of science? The framework described in this paper was designed as an analysis tool to help us interpret our interview data. However, the framework could also be used as a pedagogical tool to help practitioners and researchers make explicit the implicit curriculum messages being communicated by university teaching. Beneath the level of curriculum, the framework may also help practitioners to interpret the epistemological and sociological positions exhibited by their students during tutorial discussions and laboratory work. Highlighting the issue of images of science with lecturers and students is an important step towards developing an undergraduate curriculum which adequately represents science to students.

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Figure 1: A framework of students' epistemological and sociological reasoning about science

A The relationship between knowledge claims and data

Aa Knowledge claims as description
No appreciation of theories and concepts as constructions.
No clear separation between description and explanation.

Ab Knowledge claims as provable
Knowledge claims recognised as separate from data, and provable:

(i) on empirical grounds:
- a Mention of meticulous procedures for ensuring reliability of data, and hence the validity of conclusions;
- b Mention of 'critical experiments' to distinguish between theories.

(ii) on social grounds

(iii) Recognition of difficulty of absolute proof

Ac Knowledge claims go beyond the data
Knowledge claims recognised as involving conjecture:

(i) Social processes involved in evaluating theories;
(ii) Empirical processes involved in evaluating theories;
(iii) Both social and empirical processes involved in evaluating theories;
(iv) No obvious basis for evaluating competing knowledge claims.
(v) Recognition of logical difficulty of absolute proof, as opposed to logical possibility of falsification

B The nature of scientific lines of enquiry

Ba *Location in individual interests of scientists*
Lines of enquiry are based solely on the personal interests of scientists.

Bb *Internal location in epistemology of discipline*
Lines of enquiry are intellectually located - i.e. in terms of an ongoing process of generating ideas and questions.

Bc *External location*
Lines of enquiry are socially located - i.e. in terms of questions of broad social relevance:

(i) Utilitarian: for 'the greater good';
(ii) Financial: in terms of financial viability.

C Science as a community of scientists

Ca *Individualist view*
Scientists are essentially individuals working in isolation; no recognition of a community of scientists.

Cb *Recognition of a community of scientists*
Awareness that other scientists may work in the same field and interact with each other.

Cc *Recognition of the institutions of science*

(i) Financial interests of various institutions recognised as having some influence over the range of work that is done;
(ii) Community of scientists recognised as having a role in the validation of public knowledge;
(iii) Named institutions, or processes such as peer review recognised as having a role in the validation of public knowledge.

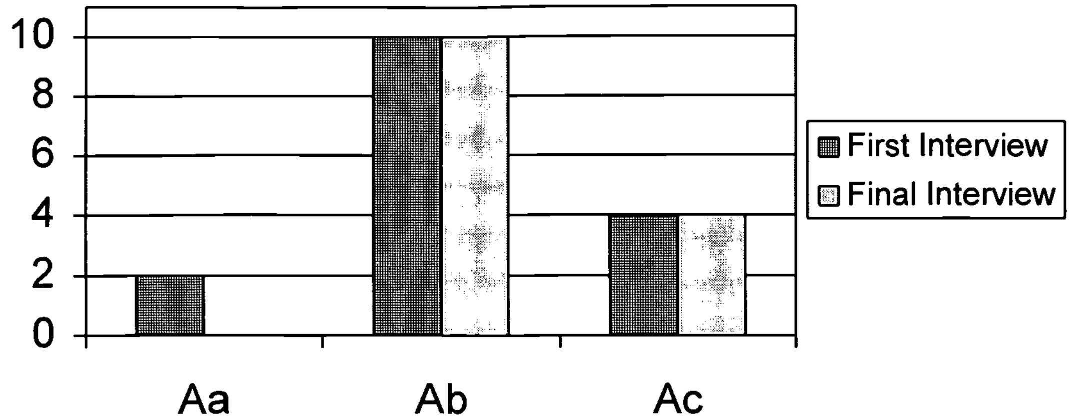

Figure 2 The relationship between knowledge claims and data

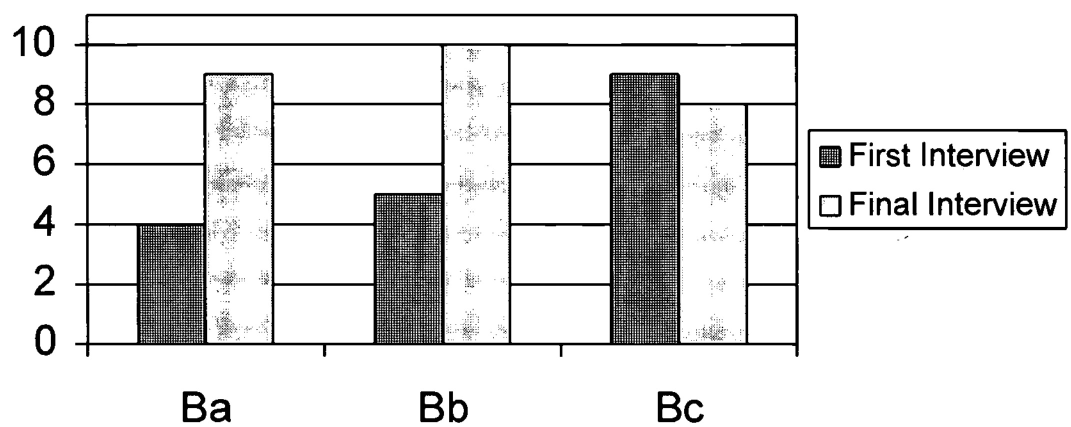

Figure 3 The nature of scientific lines of enquiry

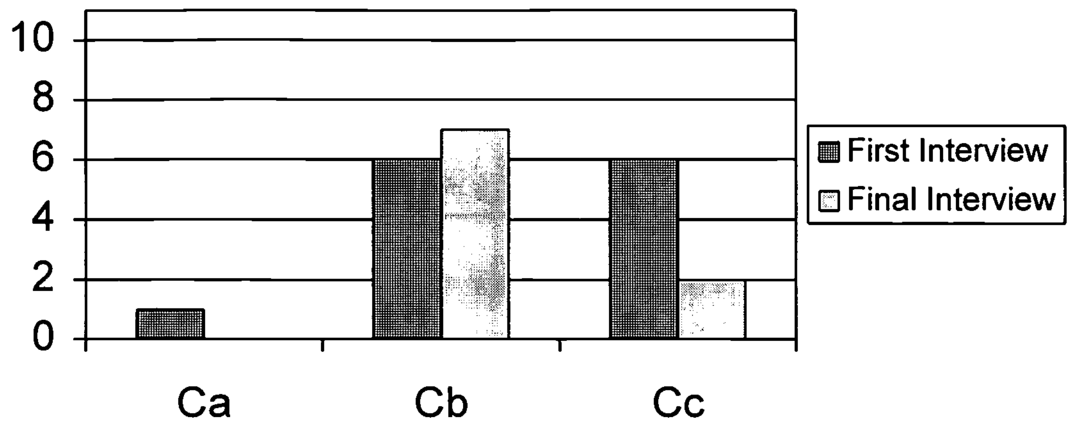

Figure 4 Science as a community of scientists

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