Undergraduate Learning in Science Project

Working Paper 6

Three case studies of student and supervisor experiences during undergraduate science research projects

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Abstract

The Undergraduate Learning In Science Project (ULISP) started at the University of Leeds in September 1994. Project members include educational researchers, lecturing staff within various science departments and others with interests in teaching and learning at the undergraduate level. The aim of the Project is to inform understanding of science teaching and learning at the undergraduate level, through a variety of research activities.

The Research Project Study was a two year ULISP research investigation into final year undergraduates experiences during project work. The results of this research study are reported in ULISP working papers 2 to 8.

This paper presents three separate case studies each describing the experiences of a single student-supervisor pair. The intention is draw out for each case the subtle interaction between the student's experiences, the supervisor's experiences, the progress of the project and other features of project work. The case studies each represent very different kinds of project experience.

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Contents

1 Introduction

1.1 Research projects in the undergraduate curriculum

Final year research projects are a major part of science degree courses in the UK. These projects last several months and contribute up to one third of each student's workload in the final year. Research projects can give students a unique insight into the scientific culture of their discipline. Students at the University of Leeds work on an original research question - one usually associated with the research programme of the lecturer assigned to supervise the student. For many students this is the experience which will help them to decide whether or not they wish to advance to Ph.D. studies. For other students, research projects help them to see how some of the knowledge and skills acquired earlier in their course are used to advance understanding in their discipline.

Research projects are a unique part of an undergraduate degree. Lectures, tutorials and practical classes will not fully prepare students for the demands of project work. Students need to develop a working relationship with their supervisor and possibly with Ph.D. students and laboratory technicians. Students must also immerse themselves in the research literature associated with their project, they must be self-motivated and they must be prepared to battle through in the face of many disappointments over a long period of time. For supervisors too, research projects present a major challenge. At Leeds University most lecturers have at least four undergraduate project students to supervise. They must build up a picture of the capabilities and weaknesses of each of these students. Furthermore, projects can often run into unexpected difficulties or changes of direction, and supervisors must be ready to respond to these.

1.2 The Research Project Study

The Undergraduate Learning in Science Project has undertaken a variety of studies into undergraduate learning. The Research Project Study is a longitudinal, case study analysis of student and supervisor experiences during project work. This study was designed to analyse the complex interactions between student, supervisor and project discussed above.

Full details of design and methodology are given in working paper 2 (a full list of working papers is given in appendix 1). Twelve students from the four science departments involved in the project were followed over the entire period of their projects. Students were interviewed on three occasions - at the start of their project, when their project was well underway, and at the end of their project. In addition, students were asked to keep a journal detailing their day-to-day experiences during project work, and occasional visits were made to students whilst they were working on their projects. Student interview schedules and details of the diary are presented in appendix 2. Supervisors of these

students were interviewed once when project work had been completed. The interview schedule used with supervisors is given in appendix 3.

1.3 The purpose of this working paper

In working papers 3 and 4 of this series we discuss aspects of project work across all twelve students and supervisors in our sample. Whilst such a cross-sample analysis allows us to characterise our sample, it does not draw out the complexities of individual cases. In this working paper we wish to focus on a few of the cases in our sample in order to:

- describe and interpret the *development* of individual students through their project
- consider the *interactions* between a student, their supervisor and their project

These cases could form the basis of future tutorials for students about to begin their own final year project. Such tutorials could help students to develop realistic expectations of the demands of research and what can be achieved in a final year project.

1.4 Research Questions

Following from the discussion above this working paper aims to address the following research issues:

1.4.1 To describe what an individual student learns from project work, paying particular attention to how the student's learning *develops* through their project.

1.4.2 To compare actual learning with the student's initial expectations of project work and their supervisor's description of the aims of project work.

1.4.3 To describe the *development* of an individual student's motivation, independence, confidence and self-esteem through their project, and how these are influenced by success in getting scientific results, workload, working environment and the student-supervisor relationship.

1.4.4 To pay particular attention to the *interaction* between supervisor and student, especially in those instances where communication between supervisor and student breaks down.

1.5 Strengths and limitations in our use of case studies as a research tool

In working paper 2 of this series we give a description of the design and methodology of the Research Project Study. This study relies heavily on the use of case studies - where each 'case' involves a single project student and

supervisor. Our use of a sub-sample of these cases in this working paper highlights a number of methodological strengths and limitations.

We cannot report the complete details of each case. Our use of periodic interviews, journals and occasional visits can only give a series of 'snapshots' of student and supervisor perceptions of a case. Although we can ask interviewees to reflect on their past experiences, these reflections will inevitably be coloured by their immediate experiences of the project. Furthermore, the need to maintain student and supervisor anonymity means that we must exclude many details of each case - particularly technical details of the scientific progress of a project. Finally, interviewees' descriptions of their views may not represent their 'views in action' - the ideas they draw upon when actually engaged in project work.

As a result of these limitations this paper does not attempt to judge each case and suggest how each project could have been improved. Rather, we wish to use our interpretations of cases to address the research issues described in section 1.4. It is then for practitioners to use these insights to improve the effectiveness of future projects.

Ideally we would have liked to present our interpretation of each case to the student and supervisor involved. This would have allowed us to compare our interpretation of the case with their interpretation. Unfortunately this proved impossible because of the need to maintain student/supervisor confidentiality.

1.6 An overview of the cases to be presented

In this working paper we present three cases from our original sample of twelve. Neither the original sample, nor the sub-sample of three, can be considered in any way as representative of the whole population (around 200 cases in the science departments involved). However, the three cases presented below have not been chosen randomly. We have tried to ensure that these cases cover all aspects of the four research questions presented earlier. In addition, the cases include descriptions of both positive and negative experiences of project work. Finally, the three students involved achieved a range of degree classifications (2:i to 2:ii).

Details of the context of each project have been provided in such a way as to preserve the anonymity of students and lecturers involved, and all names have been changed

The case of Susan and Dr. Kent allows us to focus particularly on the third research question - the development of a student's motivation and self esteem, and the influence of scientific results and workload. Susan's ability to evaluate her own performance objectively is a key aspect in this case study. The case study also describes the progression in Susan's learning about scientific research through her project, and speculates on how this interacts with Susan's images of science in general.

The cases of Carol and Dr. Rochester, and Julia and Dr. Mead focus on our fourth research question: the interaction between student and supervisor during

the project. In Carol's view, the supervision of her project was highly problematic in that she found her supervisor unapproachable. In addition, neither Ph.D. students nor postdoctoral researchers were involved in her supervision, and no other undergraduate students were working in the same area, with the consequence that she felt very isolated. Dr. Rochester did not perceive any particular problems with Carol's supervision, however, other than viewing her as a fairly quiet and unconfident student. By contrast, both Julia and Dr. Mead were very happy with their student/supervisor relationship. Dr. Mead runs a research laboratory in which postdoctoral researchers and Ph.D. students work alongside undergraduate students, and are involved in the day-to-day supervision of undergraduate projects.

In addition, the case of Julia and Dr. Mead allows us to focus on an aspect of our first research question: the way in which Julia learnt about the social functioning of the scientific community during her research project.

2 The case of Susan and Dr. Kent

2.1 Why this case was chosen:

Susan was a hard working student who achieved a 2:ii final degree. In terms of scientific results her project achieved mixed success. Susan's case allows us to probe our third research question in detail: to describe the development of an individual student's motivation, independence, confidence and self-esteem through their project, and how these are influenced by success in getting scientific results, workload, working environment and the student-supervisor relationship. Susan's motivation and self-esteem varied a great deal through the project. Major influences were the lack of scientific results and the large number of hours she worked on her project. Our case study focuses on what Susan learned from her project work and variations in her motivation for her project.

2.2 Background details

Susan was an international student in her early twenties with previous experience of work in an industrial research laboratory in South East Asia. Susan wished to start a PhD after her degree. This desire remained unchanged throughout her final year. Susan's eventual degree classification was a 2:ii.

Susan's project began October 1994 and ended in June 1995. The project was an experimental investigation involving molecular biology techniques applied to plant cells. Susan chose the project because she was interested in the science of cell division. The project took place within a small research group at the University of Leeds. Susan worked alongside four other undergraduate students whose projects were in a related subject area. However, these students all worked independently of each other.

Susan was supervised by Dr. Kent - the head of the small research group. In addition Susan was supported by Dr. Kent's PhD student. This student gave Susan considerable help, particularly with the day-to-day technical work of the project. Dr. Kent's supervision style was very personal and caring. He took great pride in making each of his five undergraduate project students feel part of his research group. Susan's supervision involved informal encounters on a day-to-day basis within the laboratory, together with formal meetings about once every week.

Susan's project accounted for one third of her final year workload. She had to fit her project work in around timetabled lectures, tutorials and examinations. This usually meant that Susan visited the laboratory every weekday and often at weekends. Because experimental runs took many hours at a time, Susan often stayed at the laboratory until late in the evening.

2.3 Progress of the project

Table 2.1 gives a timeline for Susan's project over the nine month period from the beginning to the final project assessment. The first four weeks were set aside for the preparation of a *proposal*. This included a literature review, safety assessment and work plan. Once the proposal was completed Susan was able to begin her experimental work. This continued until the end of March (except for a four week break over Christmas). Susan handed in her final report at the end of April. The project assessment ended at the beginning of June when Susan had her project viva. This involved an interview with three assessors, none of whom was her project supervisor.

The technical progress of Susan's project can be represented by three distinct phases. The timing of these phases is shown in Table 2.1. This table also shows the timing of the four interviews and the visit.

Phase one was the period up until the end of January. During this time Susan tried to isolate plant DNA by following a series of experimental steps involving the extraction of plant RNA. At the end of each step Susan checked the yield to see whether there was sufficient plant material to warrant moving on to the next step. Susan was never able to get enough material at each step to complete the isolation of plant DNA.

Phase two started at the beginning of February and continued through until the end of May when practical work had to stop. The change from phase one occurred when, following the suggestion of a PhD student, Susan completed all the experimental steps in one continuous procedure, without checking the yield at the end of each step. This worked well, giving Susan enough plant DNA to allow her to move on to the next stage - the amplification of a particular gene in the DNA. Susan repeated the amplification process many times, but was never able to amplify the required plant gene.

Phase three started at the end of March. During this time, when Susan was doing her project report, Susan and her supervisor came to understand why the amplification of the plant gene in phase three had been unsuccessful. In fact, this gene was not active in the original plant cells (they had assumed it was highly active). As a result there was very little RNA for the target gene - giving insufficient DNA for this gene at the amplification stage. Far from being a problem with experimental procedure, the failure in phase two was the result of an incorrect assumption about the starting plant material.

Throughout the project Susan's motivation varied a great deal. Despite starting confidently, by the end of phase one Susan was extremely despondent. At the start of phase two she became confident again, though the lack of product at the amplification stage caused Susan to feel despondent once again. In the final interview Susan felt that her project had achieved very little.

Month		University Terms	Project work	Project Phases	Data Collection
OCT	1	TERM 1	Preparation of proposal	PHASE 1	
NOV	2				First Student Interview
DEC	3		Experimental work		Visit to Student
JAN	4	TERM 2			
FEB	5			PHASE 2	Second Student Interview
MARCH	6				
APRIL	7		Preparation of report	PHASE 3	
MAY	8	TERM 3			Supervisor Interview
JUNE	9		Assessment viva		Third Student Interview

Table 2.1 Timeline for Susan's project

2.4 What did Susan learn from her project work?

In working papers 3 and 4 we described supervisor's and student's aims for final year research project work. This analysis identified three possible areas of student learning during project work:

a) To learn what life in scientific research is really like - either as training for a future career in science or to help the student to decide whether a research career is for them.
b) For students to learn how to apply their scientific knowledge and skills to a real scientific problem.
c) To develop general skills such as time management, planning and communication.

Areas (a) and (b) were characterised in working paper 1 as including aspects of subject matter knowledge, the methods of science and the culture of scientific research. Here we will ask what Susan learned about aspects (a) to (c) during her project.

2.4.1 Student projects are part of a broader research programme

This learning outcome is part of aspect (a) - what science research is really like. In both the first and last interviews, Susan showed that she was well aware that her project was part of an ongoing research effort:

"There are actually no ends to this project"
(1.71)

Susan	*I'm just doing only part of the project (..)*
Interviewer	When you say the project?
Susan	*With the whole thing which is from the beginning to the completion because I haven't completed the whole thing (...)*
Interviewer	So after you've finished now the project carries on, even though your not working on it?
Susan	*Yeah, it's got to carry on.*
(3.47-49)	

Susan also showed that she was very well aware of the existence of a research programme, where a large number of groups around the world are working to answer a single research question. Susan was aware that these groups publish their results in journals. Furthermore she felt that they were in strong competition:

Interviewer	Who in your view would be interested in the results of the projects?
Susan	*Of course the supervisor would be really interested (...) I'm quite interested (...) I think that is about all because the rest are competing actually.*
Interviewer	The rest?
Susan	*The rest are people who are working in the same area. I mean from elsewhere, other people doing the same area. Because (...) in research, its more like a competition that all of us are working in the same area, okay let's see who gets there faster and that kind of thing.*

(1.84-84)

Susan is aware of the existence of a global research programme even in her first interview. Such an awareness probably stems from her experiences as a research assistant in an industrial laboratory. Her project experiences consolidate this awareness.

A key influence on Susan's learning in this area appears to be the informal discussions that she has with her supervisor and the PhD student associated with her project:

Dr. Kent	*In view of a machine, she's a small cog really. An important one maybe but as a cog a small one.*
Interviewer	I think from practice its actually quite difficult for the students to see that image. What have you found has been useful and effective in giving Susan that image that's she's a "small cog in a big machine?"
Dr. Kent	*Oh because we talk and we talk and we talk and we talk non-stop. You see every week we met once, we talk about these things...*

(sup31-32)

2.4.2 Scientific research involves drawing together a variety of research results

This learning outcome is closely related to the one above. However, the emphasis for Susan was the extent to which good research involves drawing together different parts of *her own project* to build up a coherent scientific explanation. Again Susan's awareness of this issue is part of her learning about what scientific research is really like (aspect (a)).

> *"...you're still short of knowledge as in you haven't come to the stage that you can pull all the knowledge together to prove that this is true because*

> *you can never do that straight away, you've got to build up very slowly."*
>
> *(1.124)*
>
> *"In a way [an experiment] might not completely answer your question, it might come in different bits (...) it's just like a jigsaw puzzle, everything comes together to get a clear picture of what's happening."*
> *(3.60)*

Once more, Susan expresses this view in both the first and last interviews. Her learning in this area is consolidated by her project work.

2.4.3 Informal exchange of ideas is an important part of good scientific research

This third learning outcome is also part of aspect (a) - learning what science research is really like. Susan felt that informal exchanges were very important, particularly with PhD students:

> *"I think it is quite a good idea [to] keep in touch with the people around you in other labs (...) you might have been doing this step all the time, using this particular method but there might be a better way of doing things in another way (...) talking or having a little chat with somebody else, from other labs, you might get some other ideas."*
> *(2.66)*
>
> *"[One of my] strengths [was] picking up ideas from people. In the lab, in papers. (...) you try to get experience, or you get information on what people have done before and it does help in my project.."*
> *(3.91)*

Susan did not talk about the importance of such exchanges when asked about 'good scientific work' in her first interview. Susan seemed to learn about the significance of such exchanges entirely through doing her project. Unlike the previous two learning outcomes, Susan's learning in this area showed a great deal of *progression* through the project.

The transfer from phase one to phase two was a key time when Susan learned about the importance of informal exchanges. A chance discussion with a PhD student caused Susan to attempt the extraction of plant RNA in one continuous procedure. This helped Susan to advance with her project.

Susan's learning about informal exchanges was also helped by the informal, social atmosphere of the small research group she was working in. Indeed her supervisor felt that such an atmosphere was very important and deliberately tried to encourage such informal exchanges.

2.4.4 Laboratory protocols do not necessarily work first time

A laboratory protocol is a sequence of instructions describing how to follow a certain experimental procedure. Susan learned a great deal about the use of laboratory protocols during her project. Such learning relates to aspect (b) - students applying knowledge acquired in the first two years of their course to an original research problem.
In the first interview Susan seemed to feel that if the protocols were followed closely then their would not be any problems:

> *"There is a particular protocol that you are supposed to follow (...) that eliminates a lot of problems. A lot of mistakes you might make (...) they've got a list of problems you might encounter along the way - why do you get some of the results and not others? They sort of explain to you (...) we call it the bible."*
> *(1.61-65)*

However, by the final interview Susan had come to realise that using protocols in an original research investigation is very different from using them in the second year teaching laboratory:

Interviewer What surprised you about the project work?

Susan *I was quite depressed because (...) things that I've done [before] didn't really work out (...) I've seen people doing it and it seems so easy to them and it's got results (...) certain solutions work very well if you carry out this particular procedure but not very well if you do something else..."*
(3.104)

2.4.5 Good planning and time management are very important

Susan learned a great deal about the importance of planning and managing time on her project (part of aspect (c) - learning general skills).

At the start of the project Susan described good science *as "putting time into the project"* (1.103) without any description of how this time should be used. However, in the final interview Susan described one of her weaknesses as *"too much time being put into the project"* (3.90). At this stage she had become aware that it was how you planned and used time, rather than the amount of time spent, which was important.

Susan's supervisor was aware of this weakness in Susan:

Interviewer Would you have approached the project slightly differently from Susan?

Dr. Kent *(...) I would have changed my course of action [sooner] because she's done [the experimental procedure] four or five times, and she's becoming a little frustrated at this stage: 'I know the technique, I have done this before, why can't I see the product?' (...) she didn't say that [but] you could feel it.*

Susan would spend a considerable amount of time repeating procedures, where she would have been better stopping and using her time to think through why procedures were not giving the desired product. In this sense Susan is learning about the importance of effective planning and time management. However, whilst these are often described as 'general skills' good time management on Susan's project required a deep understanding of the science underlying the protocols that she was following. Whilst skills such as time management and planning are clearly of general *applicability* their practice requires a detailed understanding of the context involved - in this case the science of DNA extraction from plant cells.

2.5 Variations in Susan's motivation towards her project

In this section we concentrate on our third research question and attempt to describe the development of Susan's motivation and self esteem through her project. In particular we will describe how these were influenced by Susan's success in getting scientific results and her workload on the project. This focus on the *affective* domain (attitudes, beliefs, values, opinions, interests, motivation) contrasts with the broad focus of the previous section on the *cognitive* domain of project work (acquisition of facts, development of problem-solving and reasoning skills).

Susan's motivation towards project work varied enormously through her project work. During her first interview Susan was very positive and enthusiastic about the work ahead of her. However, during the visit (about nine weeks into the project) she had become very disillusioned:

"[Susan] wishes she had chosen [another] project (...) Susan feels bitter and disappointed (...) Susan feels that other project students are having a better time (...) Susan feels worried about the report writing"

(Extracts from researcher's notes after the visit)

Susan's attitude during the second interview couldn't have been more different:

"Good news, I mean I am going on very well now because [I'm] in most of the weekends (...) I should say [I'm] close nearly to finishing off " (2.1)

In the final interview Susan's attitude had changed once again:

Interviewer	How would you assess your own project?
Susan	*Not very well, could have done this, could have done that (...)*
Interviewer	Sure, but do you feel that you did well, crudely speaking?
Susan	*No.* *(3.101-102)*

This simple analysis shows Susan's motivation cycling from positive, to negative, to positive and finally to negative. What caused these violent swings in Susan's motivation towards her project, and could they have been avoided? In the following sections we suggest that not getting results and overwork had a major impact on Susan's motivation.

2.5.1 The importance of getting results

In the first section of this case study we characterised Susan's project in terms of three distinct phases, based on the scientific advances made in Susan's project. Phase one was a long period of repeatedly failing to prepare plant DNA. The change to phase two was caused by a suggestion by a PhD student which allowed Susan to make rapid progress. Phase three began when a new conceptual insight changed the whole interpretation of Susan's data, and showed that for much of the project she had been 'barking up the wrong tree'.

The swings in motivation described earlier are closely related to the changes between phases as described above. Susan's motivation seems directly related to her getting scientific results. This is particularly clear at the start of phase two when Susan (in her second interview) is positively brimming with enthusiasm (quote 2.1 above) because she has been able to make progress. Whilst it is not surprising that students will be pleased when they make progress, Susan's enormous mood swings seem out of proportion with a simple pleasure at getting results.

Susan clearly had a great desire to get results:

Interviewer:	What parts of the project do you think you will enjoy the most?
Susan:	*I'm not too sure exactly (...) maybe getting the results that [I] wanted. That might be a great joy getting it." (1.67)*

> *"I am quite anxious to get results (...) you put so much expectation into one reaction that you do, and just hope for the best, but you really want to get some results" (2.148)*

Discussions with the twelve students in our sample identified a variety of reasons why they want results so badly (working paper 4). Certainly personal satisfaction was one reason. However, the foremost reason given by students was the perceived importance that results have in the assessment of projects. Susan's desire for results was influenced by this:

> *"What we wanted is results to write up our project. There won't be much things to write about if you haven't got enough data's and results to write about." (3.89)*

Susan *The results and the write ups - if you have got results that proving your point would be really good (...) In a way it's to your advantage...*

Interviewer You say that the results help you because they get you conclusions and your able to write about that. But do you think it affects how the project is assessed?

Susan *It, might show that you're capable of producing certain results or certain findings. Proving certain points (...) relate that to what you've done - all the different procedures that you've done.*

Susan believed that her lack of results would influence her assessment despite the fact that her supervisor (and literature about assessment given to students by her department) explicitly stated that students can still get a first without any results:

> *"And I promise that even if you don't get positive results, you will get a first or whatever. It will not affect your final examination result." (sup2)*

2.5.2 The desire for results can lead to overwork

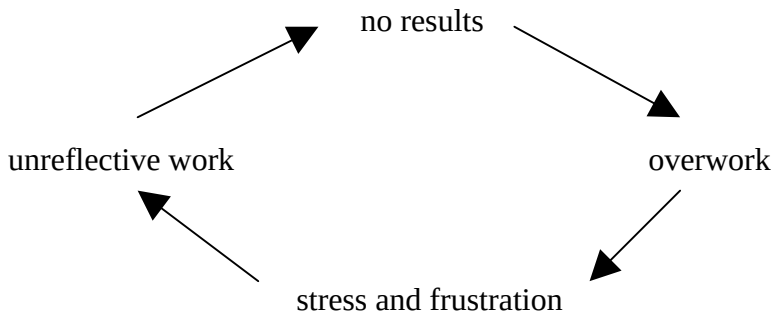
Susan worked very long hours during her project. She reported doing project work 'most days' for anything from 4 to 12 hours at a time. This included working in the laboratory at weekends. During the visit Susan was fully aware that she was working very long hours:

> *"Susan is working very long hours and feels that her [other] module work is suffering as a result." (Extract from researcher's notes after the visit)*

Susan also became increasingly frustrated that the long hours of project work were not giving her the results that she wanted:

> *"Had been working until very late (10pm to 11pm, or even later) everyday and to realise that results obtained cannot be used is very upsetting and felt tired and frustrated." (student journal7)*

We can see here that Susan's intense desire for results encouraged her to over work. In addition her other module work began to suffer. This caused her to feel increasingly tired and frustrated. As a result Susan may have been less likely to pause and reflect on her progress, and decide whether or not to follow a different strategy. Instead, as discussed earlier, Susan tended to repeat the same procedure many times in the hope that it would give results - an unreflective approach recognised by her supervisor. This approach is unlikely to help Susan to break out of the cycle of:



2.5.3 Breaking the cycle

In the final interview Susan reflected on her performance on the project:

Interviewer What about once you've written the [final] report. Do you feel that your image of the project changed in any way?

Susan *It does for me, it does (...) The way I've looked at the problem is like being somebody else (...) What could have been done and what went wrong? (...) because when your doing it you're too involved in carrying on the experiment and then your not really thinking very well - why didn't it happen? Because when I do experiments I have got this really pessimistic point of view because I'm saying that it didn't work because my tutor is no good, [or] poor handling of materials... (3.97)*

In this statement Susan implies that during her project she saw the failure to get results as a reflection of her poor technique (or poor supervising). In actual fact phase two of her project showed that attempts to amplify DNA for the target gene were misplaced - there was insufficient target DNA present. In this sense Susan obtained a *null result* - a lack of outcome which carries information about

the system under test. Instead Susan interpreted her lack of results as a reflection of her own failure, rather than an insight into the expression of the target gene.

By contrast, Dr. Kent was willing to accept that the lack of results was interesting in itself:

> *"The result as it turned out is not what I expected. And in that sense it's very interesting, but that raised several questions rather than answers. You might say 'of course when you don't get the expected results, either the student has gone wrong or alternatively there's another explanation'" (sup3)*

Perhaps the key message is for both student and supervisor to be aware from the beginning that lack of results can sometimes be due to a deep conceptual misunderstanding about the system under investigation, and that long hours of repeated experimentation will not break the cycle.

Related to the issue described above is the importance of effective communication between supervisor and student. It was striking that Dr. Kent had many positive things to say about Susan's work:

> *"..at the end when she wrote the project she came out with some brilliant ideas." (sup23)*

However, Susan still finished her project feeling that she had not done very well. It seems that Susan needed to be convinced that there were positive aspects to her work. Supervisors, and other involved in supervising the student, have a role in raising the self-esteem of students who expect too much from project work. One of the ways of doing this may be to demonstrate to students how projects without results can still obtain a first class mark - perhaps by showing them examples of previous project reports marked by the department.

What students expect from project work is a key issue. In working paper 4 we discuss how a student's preconceptions about scientific research can influence expectations for their own research project. As discussed earlier, Susan's image of scientific research emphasised the slow build up of pieces of information: 'it's just like a jigsaw puzzle'. She also described research programmes as involving many different groups tackling the same research question. These views were expressed in response to interviewer questions about the nature of science outside of the context of her research project. It is interesting to compare these espoused views with implicit images of scientific research deduced from Susan's discussion about her own project:

> *"On a results base, I don't think I [will] get a very good grade. I didn't get enough findings, I didn't really solve most of the answers - answer most of the questions that I've raised in my proposal. And I haven't completed most of my project because I intended to do much more than I've done." (3.103)*

It seems that Susan expected her short project to be successful - yielding results that could contribute to the completion of the ‘jigsaw puzzle’. There appears to be a mismatch between Susan’s espoused views about scientific research and her expectations for her project. It may be that by confronting Susan with this mismatch she could have been encouraged to appraise her own project in a more positive light, thus raising her self-esteem, and perhaps breaking the cycle of no results, stress and frustration.

3 The case of Carol and Dr. Rochester

3.1 Why this case was chosen

Carol's academic performance was assessed as being fairly strong by her department prior to the research projects. Her final degree classification was 2:i. Although she was awarded a good mark for her research project, she appeared to view the project as a negative experience overall. Indeed, at the start of her project she suggested that she was considering starting a Masters or Ph.D. at the end of her undergraduate study, whereas at the end of the project she did not want to embark on further study in science. In a survey of 128 undergraduate students, 12% stated that their research project had been 'a dreadful experience' (see working paper 7 - section 9.2). During her final interview, Carol stated that the main disappointment of her project had been her poor relationship with her supervisor. Indeed, this issue had been raised in each of the three interviews carried out. This case study focuses upon the supervisor/student relationship of Carol and Dr. Rochester, and upon Carol's motivation throughout the period of her project.

3.2 Background details

Carol had started her undergraduate study immediately after completing her 'A'-levels. She had no experience of working in science other than her undergraduate studies. Her project involved analysing a secondary data source with the help of various computer software programs. The project was supervised by Dr. Rochester and related to his research interests. Dr. Rochester was the only member of his department working on this particular field, and he did not have a research group around him. Carol was his only undergraduate project student for this particular year, and hence she was completely dependent on Dr. Rochester for supervision.

Carol carried out most of her project work in a computer cluster room, rather than a research laboratory. As a result, she was not working alongside her peers, or researchers with similar interests.

3.3 Progress of the project

Carol's project started in October 1994, and was completed in May 1995. She saw her project as having 4 distinct phases. The first phase of her project (October - November 1994) involved her in reading, and familiarising herself with the software that she would be using in her project. The second phase (November 1994 - February 1995) involved her in her first activities with data. The direction of her project was changed in February 1995, due to unforeseen problems, and Carol worked on her new research question until the end of March 1995. The final phase of her project, from April - May 1995, involved writing the work up.

3.4 How did the relationship between Carol and Dr. Rochester develop during the project?

In conducting the three interviews with Carol as part of this study, the researcher involved formed a view of Carol as a shy, fairly reticent person as shown in the following extract from notes made after the first interview:

> *Carol was quite shy/unsure of herself. She tended not to 'think aloud' around questions when an easy answer didn't come to mind.*

Carol proved quite difficult to get hold of for interviews, as she did not tend to respond to messages. Indeed, she did not appear particularly relaxed during the interviews.

All students in the sample were asked to keep a journal during their research projects. They were asked to send this journal to the interviewer in advance of the interview, so that issues could be identified in advance for probing during the interview. Carol did keep a journal, but did not provide it in advance of the second interview. It was, however, provided afterwards. Carol addressed the issue of her project's supervision in this journal. The following note made by the researcher after reading the journal indicates Carol's level of despondency at the time of the second interview:

> *Journal: This makes depressing reading - I want to call her back and sort things out! The supervision problem is clearly deeper than I thought, as is her sense of frustration with things.*

Unfortunately, Carol did not return her journal at the time of the third interview, in spite of requests.

During the first interview, Carol was asked about her relationship with her supervisor. Her first response related to her own shyness:

> *(...) But I think sometimes I would like more help but I'm a bit too shy to go and ask really.*

However, she did identify some specific points where she wanted further help later in the interview, and during the other two interviews. During the first interview, Carol suggested that her supervisor was not giving the kind of feedback that she would find helpful, but rather directing her to do particular jobs without any particular rationale:

> *(...) whereas I'm going to Dr. Rochester and he's telling me to do something and so I'm going away and doing it (...) I go and do this and take it back to show him what I've got and he tells me where to go from there.*

The issue of appropriate feedback from Dr. Rochester was raised again in Carol's second interview:

> *I find it hard to talk to Dr. Rochester... a lot of people have Ph.D. students and so on that they can talk to and they seem to get a lot more off them than I do off Dr. Rochester, and most people that I know are getting help discussing their results and I haven't had that at all.*

This contrasts strongly with Dr. Rochester's view. During an interview at the end of the projects, Dr. Rochester stated on a number of occasions that Carol's self-confidence had been an issue during the projects. However, he did not view this as having influenced the sort of feedback that he was able to give to Carol:

> *Well, as I say, she lacked confidence, she was fairly insecure for the first part of the project, she was working mainly one floor down, not far from me, so she could actually get up and find me if she had any problems. So we met fairly regularly and talked through progress and where to go from there (...) and what kind of analysis we wanted to do and how to do it ... (...) Well, basically it's discussing regularly with Carol her results and her direction and her problems.*

During the third interview, Carol stated that she didn't think that Dr. Rochester knew the time that she had put in to her project, and that generally she would have welcomed more encouragement from him during the projects:

> *I don't think Dr. Rochester really understands the amount of time I spent on my project. (...) I think he might underestimate because I want to see him so little during the second term, whereas other people perhaps other people worked with their supervisor...*
>
> *I suppose Dr. Rochester could have been more encouraging and more enthusiastic..*

Again, this contrasts strongly with Dr. Rochester's view. He stated explicitly and at some length how he had attempted to boost Carol's motivation:

> *(...) You always start by praising something and then, you know, having boosted them initially you can then have them in a state where you can actually make constructive criticisms of what they've done. (...) She came to me sometimes looking very worried but once she'd been reassured that things were going productively, we could start looking at the detail.*

Carol summed up her personal relationship with Dr. Rochester during the final interview:

> *Not very good! (...) I think it probably deteriorated a bit in the second term. I'd put off going to see him because I just felt very awkward going to see him. (...) When I went to see him the second term I felt like I was wasting his time and he didn't want to be there, it seemed like he wanted to get me out the door as quickly as possible so that made me a bit scared to ask him questions when I got stuck but now I force myself.*

Dr. Rochester's view of the supervision process was rather different:

> *Our meetings, I think, have been productive, constructive and the end result shows that something worked.*

Later in the interview, Dr. Rochester commented on his inter-personal approach to supervision

> *I don't think that at any stage I was counter-productive. I think most of the time I was able to be reasonably constructive.*

It is interesting to note that Dr. Rochester initially judged the success of the supervision process in terms of the end result of the project, whereas Carol referred more to her relationship with her supervisor.

3.5 How was Carol's motivation affected?

In general, Carol's feelings towards her project were fairly negative. During her final interview, when asked for her overall feelings about her project she said that she was 'glad that it's over and done with'. There seem to be a number of factors which influenced her motivation during the projects, including the nature of scientific research, the influence of pragmatic problems, social isolation and workload.

3.5.1 Influence of Carol's view of the nature of scientific research

In both the first and third interviews, Carol suggested that she did not see her project as being 'real' scientific research because she was using secondary, rather than primary data:

> *(...) Everybody else has got a lab. to work in and they go in there every day and they do like dilutions.. or things like that... (...) I don't feel like I am doing research. I feel like I'm just playing around really on the computer.*

> *I feel like I haven't actually done the actual research myself because I didn't find out the DNA sequences myself. (.) I was just interpreting data rather than actually finding data out for myself.*

It is possible that Carol did not see her project as being 'real' research, and did not therefore feel motivated towards it. The broader significance of students' images of scientific research is explored in working paper 5.

3.5.2 Influence of pragmatic problems

Carol experienced a number of pragmatic problems during her project which may have influenced her motivation towards it. These included problems in learning to use the various software packages required for the work, problems in transferring data files between the packages, and problems in getting sustained access to a computer terminal in an area quiet enough for her to concentrate. In addition, she experienced a period of illness which set her behind with her work.

3.5.3 Influence of social isolation

Carol commented a number of times on the social isolation that she experienced during her project, and on how that had affected her motivation. The following extract is taken from the second interview:

> *I really don't feel that I have got anywhere and I am feeling a bit fed up about it all at the moment. (...) because I'm on the computers I feel very isolated from everybody else on my course because they are all like up together in the labs so I don't see any people apart from in the lectures and that.*

3.5.4 Relationship between project work and self-motivation

During the final interview, Carol suggested that her interest in her project had 'peaked' at times when she was drawing ideas together through reading and writing up, mainly because she was able to develop broader understandings of what the work was about.

At the end of her research project, Carol referred to the role of self motivation in scientific research:

Interviewer: What would you say are the key things that you've learnt about being a scientist during the project?

Carol: *Having to be motivated, having to have a good understanding about what you're doing. I think you have to have a general interest in it to do well. (...) I suppose I allowed myself to become disillusioned*

> *with it in the second term which I shouldn't have done and I suppose I wasn't as far as I should have been in checking my results.*

Later in the interview, Carol stated that she was no longer interested in starting a Ph.D. in science following her project experience. However, when Dr. Rochester was interviewed it appeared that Carol had not informed him of this change in her intentions:

> *(...)When I saw her last week, she hadn't as yet decided on what she wants to do when she's graduated. I think she knows what it involves now and she has shown she can do it, so I would have no qualms about now writing letters of recommendation for research posts....*

This case study highlights the range of criteria that might be used in judging the success of research projects as educational experiences. Although Carol's project was assessed as being of a good standard, in general she found it a negative experience. The differences in the perspectives of Dr. Rochester and Carol about the supervision process are striking: it is interesting to speculate as to whether Carol and Dr. Rochester could have achieved agreement about the role of the supervision process had this been addressed directly at various times in the project.

4 The case of Julia and Dr. Mead

4.1 Why this case was chosen

On the basis of her academic performance during the first two years of her degree, Julia was judged as an average student, being assessed just below the 2:1/2:2 borderline. Ultimately, she was awarded a 2:1. Her project was a very positive experience for her at a number of levels. She enjoyed the experience and had good working relationships with her supervisor and other members of his research group, and her project was successful in that she managed to get various protein chemistry techniques to work. In addition, Julia was aware of having learnt a good deal about the actual practice of scientific research during her project. This case study describes the features of Julia's supervision that seemed to contribute to the overall success of her project, and the nature of Julia's learning about the actual practice of scientific research.

4.2 Background details

Julia had started her undergraduate study immediately after completing 'A'-level courses at school, and had no experience of work in science other than her degree course. At the start of her project Julia was thinking about the possibility of postgraduate study in science after her degree course, though she was also enthusiastic about a teaching career. In the end, Julia enrolled on a teacher training course.

Julia's project was supervised by Dr. Mead. Dr. Mead runs a large research laboratory consisting of a number of postdoctoral researchers, Ph.D. students as well as three undergraduate students. Both Julia and Dr. Mead saw the role of postdoctoral researchers and postgraduates as critical to the success of her supervision:

> *(...) the lab's really good to work in I think, because they get on quite well with each other (...) the post-docs and post-grads have been like brilliant because they've like taken the 'mick' out of me if I get things wrong but they do sort of really take an interest.*
> *(Interview 1)*

> *I've always tried to run a laboratory where there's a very strong team element because that way you get synergy (...) Julia and Peter were effectively working on the same preparation, different parts of it (...) it meant that they didn't have to sit alone, they could do things together.*
> *(Supervisor)*

Julia's project started in October 1994 and was finished in May 1995. During that period, there were two main phases of data collection (October

1994 - February 1995; February - April 1995), as well as a writing phase at the end of the project.

When describing Julia's progress on her project, Dr. Mead emphasised the contribution of her outgoing personality and good interpersonal skills. Indeed, the researcher conducting this case study noted her lively personality and willingness to engage in extended, thoughtful and humorous conversations about her project. At a number of points in the interviews, Julia suggested that a major source of motivation for her was the positive social atmosphere of Dr. Mead's lab, and the support and encouragement that she had been given throughout the project:

> *I like working in the lab anyway. I like the sort of involvement. (...) I really appreciate having people I can talk to. I just can't stress how important that is.*

Interviewer: What do you think would be the best possible outcome of your project?

Julia: *Just to know I've done it well, really well. (...) And to be acknowledged and to have Patrick [i.e. Dr. Mead] say, 'That was a really good project, I think that was really good'.*

Interviewer: And the worst possible outcome?

Julia:(...) *Feeling stupid for some reason.*

The ways in which Julia's supervision provided her with the positive reinforcement that she felt she needed will be discussed in section 4.4.

4.3 Progress of project

The aim of Julia's project was to isolate and purify a particular protein, and then cleave it for subsequent sequencing in another laboratory. The protein that she was working on was extracted from plant cells. This particular protein was well known in mammalian cells but to date it had not been shown to exist in plant cells. A demonstration of the existence of this protein in plant cells would have significant scientific implications.

At a technical level, the first activity on Julia's project involved isolating the protein. Next, proteases would be used to cleave the protein into a small number of segments, which would be sent to another laboratory for sequencing. After the protein is sequenced, it would be possible to produce and clone a section of DNA coding for the protein. The DNA sequence could be compared to known sequences for the mammalian protein, with a view to determining whether the plant protein was in fact from this class of proteins. In addition, the cloned DNA section could be inserted into a vector so that large quantities of the protein could be produced for future research purposes.

It was not anticipated that the DNA sequencing and cloning activities would form part of Julia's project, however.

From October to mid-November 1994, Julia worked on isolating the protein. For a variety of technical reasons, she had to start this procedure again in mid-November, and was able to produce a sample of sufficient quality to start work on proteolysis by February 1995. Her samples were sent to a protein sequencing laboratory in May 1995, at the very end of her project and while she was involved in writing up. At the time of submission of her project write up, she was not aware of the outcome of this sequencing.

Julia felt that she had worked to a very high standard during her project, and hoped that it would be awarded an upper second, or even first class grade. Dr. Mead also felt that the project had been strong, but was more modest about the grade that it deserved:

> *Strengths were that she was prepared to work very hard. She was very committed. She put quite a lot of time in. She thought about what she ought to do next and why she ought to do it. (...) Weaknesses: she didn't always think as far ahead as she ought to have done. She didn't necessarily have the intellectual input. I think to be fair she probably had the intellectual input that I would expect at her level. (...) her projected exam results... that's 2:1 or 2:2.*

In fact, Julia's final project mark was a 2:1.

4.4 What characterised the supervisor-student relationship in Julia's project?

There are striking similarities between Julia and Dr. Mead's views of the supervision of the project, in contrast to the case of Carol and Dr. Rochester. When talking about the early stages of supervision, both Dr. Mead and Julia referred to the ways in which Dr. Mead encouraged students to prepare flow-diagrams of what they would be doing on the project. In addition, Julia commented on how Dr. Mead had put her at her ease socially:

> *(...) The fact that Patrick actually turned round at the beginning and said, 'Look, call me Patrick, I'm not Dr. Mead and this is Ivan, not Dr. Walls..', and brought down a few barriers... (...) as far as supervision is concerned I think it's important to let the project students know that they are making a contribution, they are not there just to wash the dishes and to pick up a bit of research.*

We have already noted Julia's desire for encouragement and social motivation from those around her. Julia and Dr. Mead both comment on how

this was achieved during her project, mentioning the positive atmosphere of the lab in general and the role of postgraduates and postdoctoral researchers in providing encouragement:

> *(...) So the other week he spoke to Jane who's like the postgraduate and he was saying that, first of all he was saying 'how are you getting on', and then he spoke to Jane and Jane told him that she's doing quite a lot of good stuff and maybe we can get a paper out of it. So, Patrick's really encouraging them that way, he's not putting pressure on, he's just saying, you are doing well and he's recognising it. (...) I do have a lot of contact with Patrick that way.*
> *(Interview 2)*

> *I'm just about to phone two people this morning to interview them for another postdoc and one of the very important considerations that I always address is how much of a team player are they? It's extremely important that they are able to do that, able to support other members right the way down.*
> *(Supervisor)*

It was apparent at several points in the interview with Dr. Mead that he deliberately engineered a supportive social atmosphere for all members of his laboratory. Julia referred to the personal support that she was receiving from all members of the lab on a number of occasions in her journal and in the interviews.

The role of the postdoctoral researchers and postgraduates in Julia's supervision extended beyond providing personal support, however. Julia referred to the role of Dr. Mead and other members of the lab on a number of occasions:

> *At the beginning Patrick said, basically because he has got a lot of other commitments he is there as the supervisor of the whole lab, but as far as the administration and teaching and stuff he said that 'with a lot of the techniques I am not going to be around to ask questions, you are going to have to ask people in the lab how things work really' (...) Patrick said Jane, who is the postgrad, she's done a lot of work based on yours, you will be attached to Jane (...) and as far as the postdocs are concerned Patrick said Ivan does a lot of protein chemistry, you are better off asking Ivan. What Ivan doesn't know is not worth knowing.*
> *(Interview 3)*

> Interviewer: How's the supervision going?

> *(...) Principally it's Jane and Alan for everyday stuff (...) but before Jane and Alan will actually tell me something for certain, if it's not something about a solution or something, if they're not absolutely 100% sure about it they will go and check with Patrick. (...) And it is actually what they've told me but they just like to double check.*
> *(Interview 2)*

Dr. Mead confirmed that he planned for various members of his lab to assist in the supervision of undergraduate students:

> *Any project that runs in a lab of this size you generally find that people do as I do which is attach the student in some way to postgrads or postdocs and in fact my whole laboratory setting is that I have projects which devolve down from postdoctoral workers to Ph.D. students and the project students are underneath that. (...) I always see them at least a couple of times a week, I actually check out which direction they're heading in, what sort of techniques they're using, do they know who to approach or do they have the information already...*

During Julia's project, she described a number of different kinds of intellectual interactions that she had with Dr. Mead and other members of the laboratory. Towards the end of the project, Julia reflected upon the stage at which she had become able to think critically about the progress and direction of her work:

> *It wasn't until the middle that I'd discuss with Patrick intelligently and say - this salt that's interrupting this, is it because of this?.... and Patrick would say, 'That's right..' and you could see he was quite pleased because I was thinking about what I was doing and I could see why I was doing things.*

During the first interview Julia commented on Dr. Mead's 'open door' policy with project students, and how useful she had found this for getting meaningful feedback on her work. On a number of occasions, she commented on the nature of the intellectual guidance that she had received from members of the laboratory, as illustrated in the following extract from the final interview:

> *(...) if a paper came out - and a paper came out at the beginning of the year and Jane said; 'A review has come out Julia, why don't you have a read of that and this looks quite interesting (...) and Patrick was saying: 'Well, there's another unpublished result actually that they*

> *think they have got a receptor but it's not characterised enough so then we would have a little talk about it.*

Weekly laboratory meetings are a regular feature of life in Dr. Mead's lab. All members of the lab attend these meetings, and 'housekeeping' matters are routinely dealt with. In addition, each week the work of two members of the group is presented and discussed. Julia found these meetings very useful for integrating her into the laboratory, and found the experience of having to present her work useful:

> *It was quite a good exercise in that way really, to try and explain to them and, you know, Bob will turn round and say, 'Why did you do that again?' and then, 'Oh, right' - it's that sort of thing.*
> *(Interview 2)*

These laboratory meetings seemed particularly useful in introducing Julia to the place of her project in a broad line of work. This issue is discussed in section 4.5.

Throughout the interviews, it is apparent that Julia has great respect for Dr. Mead as a supervisor, and at a personal level. During the final interview, Julia commented on the advice that she would give to prospective research project students before selecting a project:

> *Go and speak to all the people who you think you are going to do the project with, ask them if you can be shown round the lab, ask if you can be introduced to a couple of people. (...) Just try and go by gut instinct, if you've got a funny feeling about a lab then it's probably true.*

When asked about how new members of academic staff learn about the supervision of research projects, Dr. Mead stated that there was no formal system though some people sought advice informally:

> *Quite often I've had new staff ask me how things go on. I don't know whether it's because this group seems to have a reputation for being fairly friendly, that people come and ask me because I have that reputation or whether they do generally. There is no formalised structure of how to supervise students and people tend to vary very much in their approach as people vary* per se.

Julia contrasted her experiences of supervision with those of some contemporaries, suggesting that departments should have some system of support for project students outside of the immediate lab should things go wrong. She felt strongly that other lecturers in her department had a lot to learn from Dr. Mead's approach to supervision.

4.5 Julia's learning about the social aspects of science

During the interviews, Julia talked explicitly about how she had learnt about working life in a university laboratory during her project. Dr. Mead also described how he structured projects to allow this learning to occur. This issue is discussed in section 4.5.1. In addition, it was apparent that Julia's understanding of the place of her project in a broad line of research had developed during the project, and it also appeared that her view of the nature of science as a social enterprise had changed at a more general level. This issue is discussed in section 4.5.2. Working Paper 5 gives further details of how individual students' images of the nature of science developed through project work.

4.5.1 Julia's learning about the world of university research laboratories

In the final interview Julia summed up her learning during her project as follows:

> *I have learnt so much from it. I did cover a lot of protein chemistry techniques I think or a lot of basic ones and what I have learned I suppose is the basis of scientific research, it's just a case of this is how a lab works and you have got to get on with it. You know, it's not a case of if you have a problem go away and ask someone, don't just panic with it, and any problem you have had someone else has had in the lab before, you are not on your own and I think that was really valuable.*

She felt that she had learnt a lot about life in a university research laboratory. At other points in the interviews, she referred to routines such as having a washing-up rota in the lab as well as the more subtle aspects of working as a member of a team alongside a range of different people:

> *(...) It would be misleading to say that everybody like, oh yes, were all friends and it obviously doesn't work like that. But at the end of the day it does emphasise to you working that way, and its quite nice to see it in practice. (...) It's nice to actually be part of it a little bit as well, and actually see it working.*
> *(Interview 2)*

In describing the nature of 'good scientific practice' in his area of work, Dr. Mead referred to the role of experience in making biochemical techniques work:

> *Intuitively I would know about some of the protein chemistry behind it, how it behaves. We're talking about science here but there is an element of craftsmanship so I*

> *would know that certain things wouldn't work on certain apparatus.*

He then went on to describe the judgment that he had to exercise as a supervisor in deciding whether to direct student in a particular direction, or whether to allow them to follow courses of action that he would not advise himself in order to allow students to learn from their mistakes:

> *If it's going to be an absolute disaster I actually say 'That's going to be an absolute disaster' because there's no point in someone totally failing, they don't learn anything. If we're in a situation where there are four approaches (a) - (d) and I would normally choose (a) and they would choose (d) I would ask them to think about it and if they still want to do it I'll let them do it because I think there is some value, not in outright failure but failure in the way that you can see why you've failed. it would also depend on the time in the project, I would much rather the students did that in the first few weeks than when they're in the final stages.*

Julia also mentioned how she had learnt about the 'tricks of the trade' that scientists use in their work:

> *I haven't actually made a mistake where no one's known what it is, Patrick's said, 'oh, boil the sample just a little bit longer so that you don't get so much collection at the top of the gel'. (...) So it's been things like tricks of the trade really that they've picked up themselves.*
> *(Interview 2)*

4.5.2 Julia's learning about her project's place in a broad research programme

At the beginning of section 4.3 we describe how Julia's project relates to some ongoing lines of molecular biological research. During the first interview, it was clear that Julia had a general understanding of how her project work related to the work of a number of other members of the laboratory:

> *I think Pete, another boy in my year, is actually going to be working on the protein whereas I'm working on the receptor end of things. I think Alan - a postgrad - is working on auxin reception....*

However, there is little indication at this stage that she sees her project as having a significant place in a broad research programme:

> *I think basically it's just to give me a run through for techniques, especially as I may be doing a Ph.D...*

When asked how project work is identified, and about who would be interested in the results of her work Julia gave no indication of seeing the project as relating to a broad research programme.

This contrasts strongly with Julia's comments about her project during the final interview. The following response was given to a question about who would be interested in the findings from her project:

> *Well, it's commercially not that important I think, not now. Patrick's lab isn't particularly an applied lab if you like. In about five years' time I mean how this information could be used if it was characterised as a receptor and that was 'full stop' then that's fine that would be academic accolade you know your first receptor found in plants that would be great. But until it can be targeted by toxins or herbicides those sorts of things - I suppose especially in plant biochemistry, until it can be picked up by industry then that's when the find in itself gets some weight. (...) if perhaps this procedure has isolated one receptor can be used to isolate others, or if not just receptors what about other parts in the pathway and things like that . Really I think you are looking at 15-20 years down the line before the information will be used like the mammalian counterparts.*

Commercial significance is discussed in some detail here. Julia's comments about the significance of the plant proteins compared to their mammalian counterpoints were further developed:

> *Well a lot of techniques used in plants have come directly from mammalian studies, there is a protein receptor found in the eye and they know that that pathway has been pretty much delineated, so I suppose those kind of studies would transfer over to plants. To first of all see whether..... there is a whole wealth of things really to see where [these] proteins are distributed within the plant cell, if they are found within all species or whatever, and then start to look at maybe delineation of the pathways, to see what affectors are because affectors and [these] proteins would be ion channels or the receptors themselves could be activated by light as they are in the eye.*

Dr. Mead commented on Julia's understanding of how her project related to other areas of work in the field:

> *Really based on reading her project write-up she seems to have her head around things fairly well. (...) The first*

> *thing that takes place in any of our projects is directed reading and then after that they're told to look out for any information in the library (...) It didn't impinge directly on the practicals but it certainly informed her write up.*

We have already noted that Julia valued this directing of her reading. In addition, it seems from the following comment that Julia viewed the weekly laboratory meetings as being an important influence on her learning in this respect:

> *(...) it just gives a chance really for the postgrads to let people know how they're getting on, but also, although there is interaction within the lab, to ask other people questions and things. (...) It's very much a lab where everything's quite integrated (...) There's very much a consciousness of working as a lab really...*

During the first interview, Julia suggested that lines of scientific work generally emerge due to commercial factors, such as whether the outcomes of research could be exploited by the pharmaceutical industry. Her comments were at a very general level however, and she made few references to the importance of particular projects within disciplines. In contrast, during the third interview Julia presented a more elaborated argument in which the commercial significance of research is recognised as well as its significance to a discipline:

> *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. If it's the development of a drug and they have found, say there is a group attached to it then they will obviously see if other drugs affect it, or create this drug again or rational drug design that can be followed along those lines 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.*

5 Discussion

5.1 What did these students learn about science during their projects?

Research questions 1 and 2 in section 1.4 refer to what students learn about science through project work and how this learning compares with students' expectations and supervisors' teaching aims. Our discussions with supervisors (see working paper 3) has shown that student learning during project work is intended to be focused on issues of research procedures and research cultures rather than on the subject matter knowledge of the discipline. To what extent is such learning about the procedures and cultures of scientific research evident in the three case studies presented here?

Section 2.4 shows that Susan learnt a great deal about the existence of research programmes in scientific research and how effective research involves talking to other researchers. Section 4.5 shows that Julia learnt an enormous amount about the social aspects of scientific research - particularly the internal workings of an active research group. In both cases a key feature which enabled such learning to take place was the immersion of these two students in an active research culture[1]. Julia was part of a large research group in which there were a number of people with whom she could discuss her project work. Having people constantly on hand to discuss technical issues of how to make an experimental procedure work, or scientific work which was related to her own project, helped Julia to learn about research programmes and how they develop. Susan, though in a much smaller research group, also described how she was able to talk to her supervisor about how her project fitted in to research work going on elsewhere. Susan's previous experience in an industrial research laboratory was probably another important factor contributing to her learning about the culture of scientific research.

By contrast Carol demonstrated a much less developed understanding of the scientific research culture. Carol's project is characterised by her social isolation and her generally low self-esteem. It seems likely that the lack of opportunity for Carol to talk about scientific research with others contributed to her limited learning about the scientific research culture. This does not mean that an active research group is the only form of research culture. Carol's project is the sort of work that many active research professionals are engaged in. However, our case studies do suggest that an active research culture is the best environment in which to *learn* about scientific research. The issue of how students can learn about the procedures and culture of scientific research in the absence of active research groups is explored in section 5.3.

Another key area which all three students learnt about through project work was the difficulty of applying standard techniques (either experimental or

[1] For further discussion of the influence of enculturation on student learning about science see working paper 1 and Ryder and Leach (1997) 'Research projects in the undergraduate science course: Students learning about science through enculturation' in Proceedings of the 4th International Improving Student Learning Symposium, Oxford Centre for Staff Development

computational) to new materials or new forms of data. In traditional university teaching laboratories students are virtually guaranteed to get results during the time allotted (usually no more than one day). This gives students an image of scientific research as a relatively unproblematic application of routine procedures. However the three projects described here represent original scientific investigations. The students are exploring new areas and as such are almost certain to encounter difficulties - many of which may prove insurmountable even over the extended period of project work. Indeed Susan's project was prevented from advancing from the outset owing to an incorrect assumption taken when the project was set up - a fact that both Susan and Dr. Kent were totally unaware of until the project was completed. Thus, the difficulties and blind alleys of research was a feature made evident to all three students during their projects.

5.2 The influence of project work on student motivation and self-esteem

Research questions 3 and 4 presented in section 1.4 consider the development of student motivation and self-esteem through project work and how motivation is influenced by features of the project - notably whether the project yields results and the nature of the student-supervisor relationship. All three students in our case studies show variations in motivation through their project work. In many cases these variations can be related to particular features of the students' experiences.

As described in section 2.5 Susan showed considerable variation in her motivation. Making progress on her project was a major source of motivation for Susan. Because Susan's project went through long periods of not making progress she was at times extremely demotivated. Section 2.5.1 showed that Susan's need for results seems to be related to her desire to get a good mark for her project. This raises the issue of student's conceptions of the project assessment process and whether assessment is dependent on results. Despite reassurances from her supervisor and in departmental literature Susan still felt that she could not get a good mark unless her project made progress.[2] This caused her to overwork and feel stressed about her project.

The cases of Julia and Carol also show variations in student motivation. However, in these cases the nature of supervision and interaction with others seems to be a more important influence than whether or not their projects were getting results. In fact both Julia and Carol both made fairly steady progress in achieving scientific results. These two students received very different forms of supervision. Dr. Mead (Julia's supervisor) was very explicit about how he tries to make his project students welcome and part of the team. By contrast Dr. Rochester places less emphasis on the student's enculturation into research work, seeing a successful project as one which achieves useful scientific results. In addition to supervision style, Julia is able to interact continuously with more experienced researchers. This interaction is a source of motivation for Julia - she receives praise, encouragement and advice whilst doing her project. By contrast

[2] Section 6 in working paper 4 gives a full account of students' views of the assessment process

Carol has little opportunity to talk about her project with anybody other than her supervisor.

A further feature which seems to influence the motivation of students in these case studies is their ability to appraise their own performance realistically. At times Susan felt that her performance on her project was very poor despite her hard work. This proved to be very demotivating. However, Dr. Kent describes how Susan often came up with some very good ideas. Furthermore, the lack of results proved to be entirely independent of Susan's work on the experimental techniques, but the result of an incorrect assumption taken by her supervisor in setting up the project. Thus, in order for students to be able to make a realistic judgment of their performance they need to be aware of how professional research often progresses not in a smooth linear fashion but very haphazardly, often following blind alleys. Working paper 5 discusses in detail individual student's images of scientific research and how these can be influenced by project work.

5.3 General implications for courses involving research projects

Whilst the three case studies presented here were deliberately chosen to cover a wide range of issues they can in no way be considered as representative of student projects. As a result we must be very cautious about drawing general conclusions from these three case studies.[3] However, our discussion above has highlighted several issues which are of central importance for project work. Many of these issues can be seen as aspects of the more general issue of *effective communication* between the student and those involved in their supervision.

Our case studies highlight three broad areas which should be covered in communications with students. Firstly, students need technical guidance about how to make procedures work, how to interpret experimental or computational outcomes and what technical procedures to perform next. These issues are directly related to the scientific questions which define their project. Students and supervisors both feel that these issues are important, and a great deal of time is spent discussing them.[4] A second area of communication is about the procedures and cultures of science. Which are the important research papers relating to the project, what is the history of research in this area, how did the supervisor's interest in this project arise? These issues are related to the scientific work of the project but they are one step removed from the technical day-to-day issues described earlier. A third area of communication is about affective issues - those relating directly to students' feelings and attitudes rather than their learning about science. Such issues include whether the supervisor thinks that the project is going well, whether the student is aware of how the supervisor views their performance, or whether the supervisor is aware that the student is overworking or worried about getting scientific results. During busy

[3] Working paper 8 draws on all of the twelve case studies and the surveys of students and supervisors to present some general issues and implications for undergraduate science project work.

[4] Section 7.3 in working paper 7 gives a full account of the content of student-supervisor discussions.

project work communication about these affective issues often gets neglected. A key message from the three case studies presented here is that such issues can have a big impact on the student's learning about science through project work.

Given the importance of the three areas of communication outlined above, how can those involved in project work ensure that students have the opportunity to discuss issues across all of these areas? Our case studies show that discussion about technical issues is a common feature of student project work. However the cases of Julia and Carol highlight the differences with respect to communication about the procedures and cultures of science. Dr. Mead would discuss the 'state of the field' with Julia, and ask her questions such as 'what would you do next?' In addition Julia was able to interact with the PhD students and postdoctoral research students around her. They would discuss how they became interested in a particularly research question and how the research area had changed or developed in recent years. By contrast Dr. Rochester's discussions with Carol tended to focus on what she should do next, with little discussion about the broader relevance of her work, or how it fitted in to a global research programme. Although Carol's lack of awareness of research procedures and cultures was exacerbated by her social isolation this lack of communication was certainly not inevitable. Other of the twelve case studies show students who learn a great deal about the procedures and cultures of their discipline despite having only their supervisor to interact with.

The third area for communication is about affective issues. Both Susan and Carol stated at various times in their projects that they felt that they were doing very badly. This often contrasted with their supervisors' reflections that in fact they were doing rather well. What makes Carol's case of particular concern in terms of effective communication is that her supervisor seemed unaware of the considerable stress and discomfit that Carol was feeling. Julia's case shows Dr. Mead ensuring that Julia receives praise and encouragement when appropriate. Dr. Mead had an explicit awareness of the importance of monitoring his students' attitudes towards their project work.

Our case studies have highlighted the importance of the student being able to talk about their project, and scientific project work in general, with other more experienced researchers. Communication across all of the three areas outlined above seems particularly effective when the student is able to interact continuously with a variety of people, including their supervisor. Whilst this immersion in a scientific culture - typified by Julia's experiences - may be the ideal it is not the only form of successful project. There are many other ways in which students can talk about research procedures, research cultures and their overall feelings about their project work. One possibility is for students to discuss project work with their peers in tutorial groups. Such an approach has been used successfully with project students in the department of Physics at the University of Leeds. Such peer tutorials could be semi-structured to ensure that students talk about their 'field of research' rather than merely focusing on the technical details of their own project. Such tutorials could also include students talking about whether they felt they were doing well. In this way students can become aware that hardly any of their peers have any meaningful results at the

half way stage of project work. Elsewhere in the undergraduate curriculum we have seen approaches which encourage students to reflect on the procedure and cultures of scientific research. Tutorials in the Department of Earth Sciences include discussions about how to find research articles, how to read them effectively and how to present a précis of the main findings to either a scientific or a general audience. Other possibilities include guest lectures from scientific researchers along the lines of ‘how I became a scientist’ or ‘why I became interested in xxxx and how research in this field has developed’.

Appendix 1: ULISP Working Papers

As part of the dissemination of research findings to ULISP participants and others interested in teaching and learning of undergraduate science, a series of working papers has been prepared. Details of these are given below.

1 A perspective on undergraduate teaching and learning in the sciences

This paper sets out the perspective which participants in the Undergraduate Learning in Science Project have developed towards the broad range of issues associated with undergraduate teaching and learning in the sciences. The paper draws upon discussions within ULISP and is informed by the studies that ULISP participants have been involved in.

2 The Research Project Study: Design and Methodology

Focusing on the Research Project Study this paper gives an account of the design of the study. It also includes the reasons for designing the study in this way and the limitations and strengths of the data obtained.

3 Final year projects in undergraduate science courses

This paper gives an account of the role of projects and how they have been implemented in departments as discussed in the interviews with supervisors. The paper covers the suitability of projects for undergraduate work, the allocation of projects to students, supervision of students and assessment of projects.

4 Undergraduate science research projects: The student experience

This paper focuses on students' views and experiences of projects. Using interview data and entries in personal diaries a variety of issues are addressed from the student's perspective.

5 Undergraduate research projects and students' views of the nature of science

This working paper focuses on the students' views of science and science research as discussed in the interviews.. What themes are evident in the students understanding of science? In our sample of students how do views of these themes develop in time? For particular students how do their views of science develop through the research project?

6 Case studies of science students doing undergraduate research projects

Several detailed case studies from the Research Project Study are used to highlight particular features concerning research projects in the undergraduate curriculum. These can be used as a teaching resource for use in tutorials with second year students.

7 A survey of students' and supervisors' experiences of research projects in undergraduate science courses

Following from the 12 case studies reported in working papers 2 to 6 a survey was designed and administered to students (N~250) and supervisors (N~120) at the University of Leeds. Results and conclusions from this questionnaire survey are presented in this paper.

8 Implications and messages arising from the Research Project Study

This paper reflects on all of the work described above. It attempts to summarise the salient features and draw some implications of these findings for undergraduate teaching in the sciences.

Appendix 2: Interview schedules used with project students and information on the completion of log books

Interview I: Administered at the beginning of projects

A Details concerning the research project and the student:

A1 Tell me about your project, bearing in mind that I am not a specialist.
A2 Is your research project related to other work in the department?
A3 In your view what is the main aim of your project?
A4 Have you ever worked as a scientist outside of university?
A5 What do you hope to be doing after you have completed your degree?

B Project management in departments

B1 Was this project your first choice when you were deciding which project to do?
B2 What was your motivation for including this project in your choices?
B3 Are you satisfied with your project allocation?
B4 What in your view would be ideal supervision of the project?
B5 What can you tell me about how your project work is assessed?
B6 Do you feel adequately prepared to begin a research project?

C Students preconceptions about the nature of research project work

C1 Could you describe for me the kind of activities you feel that you will be involved in over the period of your research project?
C2 Which aspects of the research project do you think that you will enjoy the most?
C3 What do you think would be the best/worst possible outcome of your project.

D The purpose of research projects in the undergraduate course

D1 Why do you think that research projects are part of the undergraduate course?
D2 In your view who will be interested in the results of your project?

E Research Projects as 'real' science

E1 Do you think that your project will give you an insight into the work of a professional scientist?
E2 In what respects will your project work and the work of a professional scientist differ?
E3 How will you try to ensure that your project follows good scientific practice?

F Student's views of the nature of science in general

F1 How do scientists decide which questions to investigate? (i.e. what is the purpose of the scientific enterprise?)
F2 What is the purpose of scientific experimentation?
F3 How can good scientific work be distinguished from bad scientific work?

F4 Why do you think that some scientific work stands the test of time whilst other scientific work is forgotten?

F5 How are conflicts of ideas resolved in the scientific community?

Interview II: Administered once project work was well underway

A) What stage are you at on your project?
Ensure that this is understood in terms of the discussion about the project aims from the first interview. There may also be points from the visit which are relevant here. Follow up any new technical aspects of the project.

B) What technical difficulties have you experienced in your project? How have these problems been tackled? To what extent has the solution to these problems been within your control? To what extent have these problems impeded your progress on the project?

C) Could you describe some of the intellectual challenges that you have been faced with in your project?
E.g. thinking: the use of evidence, data interpretation, redesign of protocols, interpretation of reading, anomalies, planning of what to do next...

How have you tried to solve these problems?
Probe this in some detail - evidence of student epistemology. Use of terms such as theory, analysis, model, expected result...

D) Apart from these technical and intellectual challenges, what else has had an important impact on your progress in this project - for good or bad?
Illness/absenteeism; other university work (e.g. useful lectures, work load on other courses); interactions with other workers (personality clashes); supervision (next question)

E) How is the supervision going?
Positive points, negative points.

F) Follow up any points raised from the personal journal which have not been covered already.

G) What are your overall feelings about the project? What parts are you enjoying? What aspects do you not enjoy? Do you have any worries about the project? E.g. finishing on time, assessment...

H) Any points from the first interview which need clarifying?
E.g. work experience, a copy of the initial 'proposal'...

I) Concluding remarks

Continue to use the diary (return it to the student). Suitable period in which to do the final interview (i.e. after the assessment but not in the middle of final exams...). Does the student have any questions about the study?

Interview III: Administered once project reports had been completed

A The research project as an introduction to the world of the research scientist

A1) I am interested in what you were actually doing during the hours that you worked on your project. What different things did you find yourself doing?
Expected factors: reading, library work, making notes in work book, writing up, doing practical work, analysing the results, planning, laboratory meetings, discussions with people in the laboratory.... - apply a hierarchical focusing strategy here.
- What proportion of the time did you spend on each of these?
- If we consider your project as a single timeline from start to finish when did you find yourself doing these things? *(Use a notepad here?).*
- hours of work per week / working at weekends?

A2) Do you feel that your project has included all aspects of scientific research work or has something been missing?

A3) What were the main findings of your project?
- use examples from the student's project as a 'hook'
- How do you know these things?
- How did you ensure that your project followed scientific practice?

A4) How important are your findings?
- Who has valued your results?
- Does your work fit in with other work - either in this department or elsewhere?
- how novel are your results?
- how have you tried to acquire a 'broader picture' of the place of your project in science?
- how has your ability to control the direction of the project changed?
- If you had an extra six months what would be your research questions?

B The student's explicitly stated views about what scientific research is in general.

B1) How do scientists decide which questions to investigate?
B2) Why do scientists do experiments?

B3) How can good scientific work be distinguished from bad scientific work?

B4) Why do you think that some scientific work stands the test of time whilst other scientific work is forgotten?

B5) How are conflicts of ideas resolved in the scientific community?

B6) In what way have your experiences on the project influenced your understanding of what scientists do?
- *probe by using the student's as described in B1-B5.*
- *what are the key things that you have learnt about being a scientist through doing this project?*

C Supervision and Assessment

C1) In what ways have your views about ideal supervision changed during the period of the project? Why have they changed?

C2) Has the role of those involved in your supervision been clear to you during the project?

C3) How would you describe your personal relationship with those people who have been involved with your supervision?
- i.e. Approachable? Encouraging? Supportive?

C4) What strengths and weaknesses did you show on your project?
- what were the most difficult aspects of this project for you?
- how did you react to working in an unfamiliar environment?
- how did your performance change over the period of the project?

C5) What do you know about the criteria which are used to assess your project?
- write up
- summative assessment of project performance

C6) How did you go about preparing the final write-up?
- did you know what to include? *(especially if limited 'results')*
- did the process of writing up change your view of the project?

C7) How did the assessment of your project influence what you did on the project?

C8) I appreciate that you do not know your final mark yet but do you feel that your project (has been/will be) fairly assessed?

C9) How would you assess your own project?

- what mark would you give your project?

D General Issues

D1) Now that you have completed the project what are your overall feelings about it?
- do you feel that it has been successful? Why?
- how has your motivation towards the project changed over the year?
- what surprised you about project work?
- what disappointed you about project work?
- how has your module work influenced your work on this project?
- would you have preferred a project that was more likely to get results or was more exploratory or 'risky'? *(as appropriate)*
- Have you been pushed to work to your maximum ability on this project?

D2) What advice would you give to a third year student who was about to begin a research project?
- what do you feel could have been done earlier in the undergraduate course to make you better prepared?

D3) *(If relevant)* Did your experiences in industry influence your approach to project work?

D4) Have your experiences on the project influenced your choice of future career?
- what is your intended career now?

D5) Are there any questions that you feel I should ask your supervisor?

Information on the completion of log books

Each student was given a journal at the end of the first interview, in the form of a board-bound A5 lined booklet. The following instructions were printed on the first two pages of the booklet, and were talked through at the end of the interview:

> Research Project Study - Using Your Journal
>
> What is the Journal?
>
> The aim of this Journal is to encourage each participating student to keep a regular record of their thoughts, feelings and ideas about their research project.
>
> The Journal will help you to reflect on your progress whilst providing valuable data for the Research Project Study.
>
> All entries will be treated as confidential and will remain anonymous.
>
> The Journal is **NOT** part of the project assessment in your department, and will only be consulted as part of the Research Project Study.
>
> What should I write?
>
> Anything that relates to your research project.
>
> This could include reflections on how well you are doing, problems, successes, insights into how to do good project work, 'blind alleys' you may have followed, or even comments about the Research Project Study.
>
> How much should I write?
>
> As much as you wish.
>
> We would suggest an entry every week as the minimum.
>
> A few comments after each project session would be ideal.

Appendix 3: Interview schedule used with project supervisors

A The Research Project as part of the undergraduate course

A1) What do research projects contribute to the undergraduate course?
Expected factors: develop general skills, scientific skills, understanding of the research process, understanding of scientific concepts, preparation for future career...

A2) What are the essential requirements of a project for it to be suitable as an undergraduate research project?
- How are projects allocated to students in your department?

A3) How did this particular project come about?
- where did the *idea* come from?
- is it related to other work in the department/field?
- in hindsight how would you evaluate this project in terms of its suitability as an undergraduate research project

B The student's experience on the research project

B1) What strengths/weaknesses did the student show during this project?
- what were the most difficult aspects of this project for the student?
- how did they react to working in an unfamiliar environment?
- how did the student's performance change over the period of the project?

B2) In general what can research projects tell students about the work of a scientist? (cf. question A1)
- do you feel that the student has gained an understanding of what it is like to be a scientist through working on this project?
- what image of a scientist do you have in answering this question?

B3) What are the main findings of this project?
- are these findings important? To whom?
- do you feel that the student has a feeling for the significance of these findings?

B4) We have discussed the extent to which the research project has given the student a sense of being a scientist (B2). We have also discussed the sense that the student has of their scientific findings having a significance in the scientific world (B3). We could describe these as aspects of the student's 'broader view' of their project. What methods have you found are effective in fostering the student's sense of this 'broader view'?

B5) How would you have approached the project if you had been doing it?
- what would you see as characterising good scientific practice for this project?

- What aspects of the student's work would you say were good scientific practice and which were not?
- what have you got that they haven't?
- (*perhaps use an example from the student's project)*

C The role of the supervisor

C1) How have you supervised this project?
- what has been your role as supervisor during this project?
- what factors influenced your supervision style for this student?
- what other approaches have you found effective with other students?

C2) How has the student reacted to this supervision?
- have the students reactions changed over the project period?

C3) What criteria have you used in assessing the performance of the student on this project?
- the write-up/report
- summative assessment of performance over whole period of the project
- are these criteria standardised/written down for your department?

C4) Clearly supervision is a sensitive balance between guidance and independence involving the establishment of a personal relationship with the student. What do you feel were the successes and failures of this project in terms of its supervision?
- *What is your evaluation of your performance as a supervisor on this project?*

C5) What image of 'being a scientist' would you wish the student to have at the end of the project?

D General

D1) Did the project go as you had expected it to?
- did the direction of the project change?
- did it achieve as much as you had expected?
- did your expectations of the student change as the project proceeded?

D2) Roughly how many research project students have you supervised before?
- how many do you do each year?

D3) What issues concerning this research project do you feel we have not covered in this interview?