Year 10 students experimenting with DNA: Is seeing believing?

Chi-Yan Tsui

Curtin University of Technology

Grady Venville

Edith Cowan University

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Abstract

The concept of genes as DNA coding for proteins remains the cornerstone for the explanation of heredity in school science. This research investigates the classroom teaching of genes as DNA through the analysis and interpretation of the discourse of a practical lesson. In the practical lesson, Year 10 students conducted a hands-on experiment to extract DNA from onion cells. The results demonstrate the ways in which the teacher and her students interacted in their classroom during the experiment. The analysis highlights the dialogic interactions between two students and the teacher. Although the experiment appeared to provide a more tangible learning experience for most students in the class than did a textbook description of DNA, or its computer multimedia representations, such experience did not contribute to their conceptual understanding of genes in a significant way. The conclusion outlines how students can benefit more from hands-on investigation as one way of representing information for learning about the complexity of the gene concept.

Introduction

This paper focuses on the teaching and learning of the gene concept in schools in the context of a DNA experiment in an independent girls' school in Western Australia. The study was conducted in 2002, almost half a century since Watson and Crick (1953, p. 42) proposed the DNA double-helix model based on Franklin's x-ray data[1]. In a paper in *Nature* on April 25, 1953, they suggested—in a short, assertive statement that was to revolutionalise forever our understanding of the mechanism of heredity—"It has not escaped our notice that the specific pairing immediately suggests a possible copying mechanism for the genetic material" (p. 737). Over the following fifty years, the DNA model has provided the single most powerful universal explanation for understanding genetic mechanisms. The discovery has resulted in the unrivalled advancement of the ways we understand biology, medicine, agriculture and other fields of science.

Now, students in secondary schools can carry out simple experiments to extract DNA like scientists. As a consequence, the Mendelian gene, a discrete and abstract concept that has been used in school science for understanding simple inheritance patterns for many years, is outmoded and possibly belongs to a bygone era of science (Venville & Donovan, 2005). On exploring the contemporary literature and interviewing nine geneticists to probe their views about the bewildering, modern, molecular gene concept, Venville and Donovan identify four major themes: (1) Genes code for polypeptide production; (2) Genetic determinism is a myth; (3) The environment impacts on phenotypes; and (4) Gene expression is controlled. Further, they conclude that the gene concept science teachers should teach at school ideally reflects simple principles and, at the same time, encapsulates the essence of the concept so that today's students are adequately prepared for making informed decisions in the age of biotechnology.

It is important to understand the role that practical work can have in helping students to develop a useful and scientifically accurate understanding of the gene. For many years practical work has played an important role in science learning at school. As early as the 1800s, school science laboratories in England were equipped for practical work (Gott & Duggan, 1995). School science primarily prepared students as future scientists and for a workforce requiring scientific knowledge. Some major aims of practical work in UK schools in the 1960s were to encourage accurate observation, to promote scientific methods of thought, to develop manipulative skills, to problem solve, to aid comprehension, to verify facts and principles and to arouse and maintain interest (Wellington, 1994). 'The student as scientist' was once a popular metaphor for learning science at school. However, when science educators moved from a position where science was seen as part of education only for the elite, to one of science for all, practical work in school science came to play a different role (Fensham, 1990). In a report about science for all, the American Association of the Advancement of Science points out five distinctive features of scientific inquiry through investigation: (1) science demands evidence; (2) science is a blend of logic and imagination; (3) science explains and predicts; (4) science tries to identify and avoid bias; and (5) science is not authoritarian (AAAS, 1989).

In Australia, classroom teaching using practical work can provide students with experience for developing their investigation skills and processes, for constructing conceptual understanding, for giving them a sense of the nature of science, and the excitement of enquiry and discovery (Hackling, 2004). However, hands-on experiments may not always provide the student with minds-

[1] On April 26, 2003, an ABC radio program, The Science Show, began with this: "This is the story of how one person's pioneering scientific contribution to molecular biology has gone unrecognised and undervalued for the best part of 50 years. But it's also the story of the human face of science, a reminder that even the most profound scientific breakthroughs are often coloured by human relationships, personalities, gender and culture. It's the story of the mysterious Dark Lady of DNA, the late Rosalind Franklin"(ABC Radio National, 2003).

on understanding of the concept being investigated. At a time when scientific literacy is the top priority in teaching and learning of science in Australian schools (Goodrum, Hackling, & Rennie, 2001), practical biology continues to play an important role in learning science.

In this paper, we explore classroom teaching that potentially contributes to the students' understanding of the concept of the gene through the analysis of the interaction between the students and between the students and the teacher during a practical lesson in which a class of Year 10 students extracted DNA by spooling it from onion cells. In particular, the focus is on a dyad of students, Lydia [2] and Andrea, as they followed instructions, collaborated in conducting the experiment and interacted with their teacher during the experiment. As Andrea was one of the target participating students in this study and one of the most outstanding students in her class, we also used some pre- and post-instruction interview data and other data to show how the experiment of extracting DNA could be connected to other aspects of the teaching and learning of genetics during the unit about genetics.

School Context

Ocean School is an independent secondary school for girls in a middle-class suburb of the metropolitan Perth area, Western Australia. The school's ethos is to maintain academic excellence in preparing girls for the changing needs of society and encouraging them to become independent learners of tomorrow's world. In particular, the school highlights the need for students to become confident and wise users of information and communication technologies (ICT) including computers and multimedia. The participating teacher, Ms Claire, was one of the two participating science teachers in a larger project. She had over 20 years of teaching experience and several years of using laptop computers in her teaching in Ocean School. There were 24 girls in her class, most of whom had English as their first language and their age was either 14 or 15 years when the research was conducted. The private school setting allowed teachers in Ocean School more freedom in developing curricula of their own. At the time of the research, the school was using a relatively new curriculum in Year 10 biology. This curriculum included genetics and focussed on DNA technology and genetic engineering. These topics were taught for about three of the nine weeks in the term, or one-third of the teaching. The DNA extraction experiment epitomised Ocean School's new approach to learning about genetics in Year 10.

Methodology

An interpretive, case-based qualitative method (Erickson, 1998; Gallagher, 1991; Merriam, 1998) was used in this study which was part of the doctoral research of the first author (Tsui & Treagust, 2003a, 2003b, 2004a, 2004b) but not included in his thesis due to length constraints. The major methods of data collection included interviewing the teachers and the students, observing classroom teaching and analysing documents and other artefacts. The data from the first author's research journals were also used to triangulate sources of data during data analysis and interpretation. Working in the same research centre at the time of the study, the second author belonged to a group of peer reviewers and advisers that supported the research. Regular discussions between the authors about the progress of the research in the case schools helped to increase the rigour of data analysis and interpretation.

[2] Pseudonyms are used for students, the teacher and the school throughout this paper.

In the study reported in this paper, students conducted an experiment to extract DNA from onion cells while classroom teaching during that week was about biotechnology and genetic engineering. As the first author observed most of the lessons during the teaching of genetics, he was in the classroom as a participant-observer when the students carried out this DNA experiment. Endorsed by the teacher, he helped to ensure the safety of the students while the experiment was in progress. With the permission of the teacher and the two participating students, two tape-recorders (R1 and R2) were used in the classroom to capture the verbal interactions during the experiment (see the figure in Appendix 1). We used aspects of Lemke's (1990) semiotic methods in analysing and interpreting the discourse of this practical lesson by positing that language plays an important role in making meanings about science concepts or ideas through verbal communications. As such, we analysed the verbatim transcripts of the interaction between Lydia and Andrea, and between them and their teacher, Ms Claire, as well as whole class discussions. Informed consent was obtained from all the participants in this research.

The classroom experiment

The classroom experiment was entitled "Laboratory Exercise-Spooling of Onion DNA" (see the students' laboratory manual in Appendix 2). The introduction to this experiment in the manual reads:

> Most people think of DNA as an impossibly small molecule. After all, it is inside a cell too small to be seen without a microscope and is further compressed into a nucleus inside that cell. It is certainly not something that students normally expect to handle during a laboratory. However, this procedure is a quick and easy way to allow you to actually see some DNA from an organism with which you are familiar, an onion.

The procedure of the experiment can be summarised in the following oversimplified steps:

1. Boil blended onion tissue with detergent and sodium chloride.
2. Cool the onion mixture.
3. Add meat tenderiser and stir.
4. Filter the mixture.
5. Add ice-cold ethanol to precipitate the DNA.

Although students had to follow the detailed instructions in their laboratory manual, interspersed within the text were hints as to why a step in the procedure was taken. The teacher also discussed the reasons behind the steps in the instructions and reminded the students as they proceeded in the extraction process. At the end of the lesson, the teacher required the students to answer the questions in the laboratory manual.

Discourse analysis during the experiment

According to Lemke's (1990) analysis, the approach to lesson activities described in the preceding paragraph is called *labwork* (p. 218) in which students are in small, cooperative groups working on tasks using apparatus in addition to reasoning and writing. We tried to look at two ways in which students and the teacher talked science (p. xii) during the experiment. First, we were interested in

communication during the experiment as a social process which creates and sustains a social situation with a set of relationships and expectations among its participants. Second, we were interested in how science content was communicated in classroom dialogues during the labwork. Using Lemke's taxonomy (pp. 217-218) we tried to identify the following patterns of student-teacher dialogic interactions during the DNA experiment: (1) *teacher exposition* in which the teacher presented new material initially in *monologue* and then explained it further in response to student questions; (2) *triadic dialogue* in which the teacher asked questions, called on students to answer them, and then evaluated their answers; (3) *student-questioning dialogue* in which students initiated questions about the experimental procedure and then the teacher answered them; (4) *teacher-student duologue* in which there was a series of exchanges between the teacher and one student in a triadic dialogue or student questioning dialogue; (5) *true dialogue* in which teacher and students asked and answered one another's questions and responded to one another's comments as in normal conversation; and (6) *cross-discussion* in which students spoke to one another about the experiment and the teacher acted as moderator or equal participant without special speaking rights.

Results

The results are presented in a series of six episodes that correspond to the chronology of the lesson. The episodes build up a picture of the kinds of dialogues that predominated in the lesson and are analysed using aspects of Lemke's (1990) taxonomy described above. The episodes also give insight into the learning taking place as a result of the classroom experiment.

Episode 1: Teacher's Briefing

Ms Claire began the lesson with an introduction (*teacher exposition* using largely *monologue*) for the experiment as presented below (edited from transcripts of audio-recording from R1 position):

> OK girls, just a few things first, you are doing the experiment today and there are just a few safety things that we need to sort out OK? (pause and laugh) Now, you've all got the instruction sheet, I just want to show you how we are going to use it, you all need in a moment to get within your pairs, twos or threes, probably twos would go better. Then get a heat mat, a Bunsen Burner, a tripod and a gauze, and this lab is found in the back corner, you'll see them all there we'll be looking at them in a moment, OK, they're in that corner. All the other apparatuses that you'll need, (something) and things for today, is down here, OK? So basically you are following the instructions, but if we could just look through them I can just tell you a couple of things you need, it is really important that you listen.

The "OKs" were not intended to elicit any response from the students. Then Ms Claire moved on to advise students to form groups and make use of the space and resources in the classroom:

> This lab is appalling for doing experiments in because of the way the gaps are in the room undercover and inside, and there are lots of apparatuses around. So the first thing you'll have to do is find a gap with enough space around it for you to work. Now I've cleared the front bench so one group can work there, and one group can work at the other end of the front bench, so that sort of area is an adequate

area around the room. Be careful if you're moving things though, you might have to, if it's possible to move where we can put them, so you can get a work station that is clear. OK?

Before they started, she also reminded them of the safety measures to be taken as the experiment required students to boil a frothy mixture that is likely to spill if not properly controlled:

Safety glasses you need to wear when you're heating, and they're over there… The next bit is the safety bit, it says, boil for eight minutes stirring gently, you've got stirring rods there, and stirring gently means stirring gently, not racing around, and taking turns, you're in twos or threes, so your arm doesn't get tired or too hot stirring with the stirring rod… when it boils it froths up, because of the Lux flakes, OK? …you are both watching it, because it can get out of control very quickly. If it looks like it is beginning to froth up, slide the Bunsen burner from out underneath, OK? …don't light until you're ready to go and all set up, and that's the first stage…

Episode 2: Lydia and Andrea clarifying the purpose of the experiment

After being briefed by the teacher, Lydia and Andrea, like other students in the class, followed instructions to set up the apparatus for heating the blended onion in a solution of detergent and sodium chloride. While preparing the solution, they clarified with each other why they were doing particular things while Ms Claire was providing some advice from the background. This dialogic pattern is similar to Lemke's *cross-discussion*. (The following excerpt is from the transcript of audio-recording from R2 position):

(Lots of talking in background with continuous mixing sound.)
Andrea: Well, what do you think? (Why are we adding salt or sodium chloride?)
Lydia: Well…ah…because it. I don't know, just use something random… so…um…maybe it is…
Andrea: And ah…
Lydia: Yeah…
Andrea: …the salt that allows the decomposition of the…(reading from the manual).
Lydia: Um...kind of (laughs then pauses)…how does blending help us to extract the DNA? (She was talking to Ms Claire who was approaching the group.)
Ms Claire: Pardon?
Lydia: How does the blending help us to extract the DNA?
Ms Claire: Well what do you think the blending does?
Lydia: Um…well, it reacts with the…
Ms Claire: Well when you blend it, what are onions made of? Well, what is the building block of onion, of all living things?
Lydia: Cells.
Ms Claire: Cells, so what do you think blending does to the cells? Makes cell walls, or helps to sort of release the contents of the cell.
Lydia: Oh, OK.
Ms Claire: Happy? And the detergent usually helps to break down the fat and things because membranes are usually quite fatty. So the detergent helps to break down the membrane and releases the contents of the nucleus, which is the DNA. Have you got that to remember?
(Muffled talking of Ms Claire, then student laughter, and a long pause.)

As can be seen here, the *cross-discussion* started first when Lydia asked how blending helps to extract DNA with the teacher as "moderator or equal participant without special speaking rights" (Lemke, 1990, p. 217). Then the discourse turned into another short teacher *monologue* with the teacher explaining to the two students how the detergent helps to break down the cell membrane releasing the DNA in the nucleus. When Ms Claire then moved away from the students' bench, they continued their conversation while reading the instructions in the manual and clarifying various procedures and meaning with each other:

Andrea: Read the following while you are heating your blended onion. The detergent causes the cell membrane to break down and then….
Lydia: No, read it to the tape-recorder (laughs).
Andrea: OK, and emulsifies the lipids and proteins of the cell by disrupting the polar interactions that hold the cell membrane together. The detergent forms complexes with these lipids and proteins causing them to precipitate out of the solution. Oh, oh crap!
Ms Claire: You weren't watching there. Were you?
Andrea: No, we were reading. We were taping that.
(Muffled talking and laughing.)

Andrea: Anyway, NaCl enables nucleic acids to precipitate out of an alcohol solution because it shields the negative phosphate end of DNA, causing them to come closer together and coalesce.
Lydia: Are we supposed to put a book... (away from the Bunsen burner.)

Andrea jokingly mentioned the tape-recorder indicating that they were a little self-conscious as they were aware that their conversations were being recorded. However, our observations showed that they were behaving and talking quite normally in the presence of the tape-recorder. From the second episode, we can see that Lydia and Andrea, who were good friends, were able to communicate comfortably in a collaborative learning situation and make meanings from their hands-on experience by following the instructions of the manual and building on scaffolding from their caring teacher.

Episode 3: Heating and cooling by controlling two variables: temperature and time

As the experiment progressed, Lydia and Andrea had to control the temperature by heating and stirring and by clocking the time according to the instructions. The following is a snapshot of their conversation captured by the tape-recorder at position R2:

Andrea: (Talking to Lydia.) Hey, can we put that in um the…yeah and put it in and…
Ms Claire: Don't forget to stir…(stirring noise)
Andrea: This smells bad…
Lydia: Smells like onions too.
Ms Claire: Don't forget to keep an eye on the clock, and don't forget to watch for... (frothing?)

It is interesting to note that there was some "side-talk" when Andrea said, "This smells bad..." or a kind of *disengagement* (Lemke, 1990, p. 220), a tactic that students use in controlling their

behaviour indicating that they are not paying attention to the experiment instructions. As always, Ms Claire's major concerns were to remind each group to closely follow the instructions, such as stirring and taking precautions not to spill the hot mixture. While the teacher was away, Lydia and Andrea continued to follow the instructions and heat the mixture In the following dialogue during this process, it was evident they made meanings by developing justifications for the procedure alongside some "side-talk" about the annoying oil and the anticipation of getting their test scripts back from Ms Claire:

Lydia: What are we up to? (Clanking noises.)
Andrea: Heat treatment softens the phospholipids in the cell membrane and denatures the DNA-ase enzymes which, if present, would cut the DNA into small fragments so that it would not spool. (Squeaking noise and pause.)
Lydia: This is really annoying, all this oil and stuff.
Andrea: Not oil but…crap.
Lydia: All these residual, like pulp and stuff.
Andrea: Crap.
Lydia: Pulp, pulp, pulp (long muffled pause)…it smells like it is burning…OK. Cool the onion mixture to 40 degrees by running cold tap water over the outside of the beaker for 2 minutes and then placing it in an ice water bath.
Andrea: Yeah…um, it has about 2 minutes left (muffled pause). We are getting our tests back today.
Lydia: I don't want it back.
Andrea: Don't you?
Lydia: I never want my tests back.
(Muffled pause, clanking noises.)
Andrea: Look at all the stuff on the bottom, alright?
Lydia: About 30 seconds, 25, 24, 23, 22, 21, 20, 19, 18…(muffled pause)…… and 8,7,6,5,4,3,2,1, done, and then you do that. (Pause.) (Then she answered a question from another group.) Well, we have done it for eight minutes…you run it under the water (pause).
Ms Claire: Yep, you probably will wash it back, so you put some cold water in, OK, use of the hot (something) you can not burn it at the top so you can lift it like a hot pot of coffee, you can lift it down and sit it in there then add some ice. (Pause.) Girls, if you want some ice there is a lot in there…
(Muffled pause, the breaking of ice, Ms Claire's talking in background and clanking noises.)

It can be noted here that students' hands-on experiences included the use of dexterous skills, as well as their senses of hearing, smell, sight and touch. Their minds-on learning was largely focused on justifications for using the procedure. For example, heating may not destroy the DNA, but can destroy other proteinous cell contents in order to separate the DNA. In weaving their understandings about the purpose of the procedure in this episode, the language of science that the students and the teacher shared was, as Lemke (1990) puts it, not just vocabulary and grammar, but also a "system of resources for making meanings" (p. ix). The discourse during this laboratory investigation also linked to other concepts and ideas taught and learnt in the previous lessons or weeks in the classroom. Most of these were concerned with investigation skills, cell structure and properties.

Episode 4: Tolerance of uncertainty

Research into laboratory investigation of students indicated that novel tasks are high in ambiguity and risk for the students as they do not have previous experience of such tasks (Treagust, Wilkinson, Leggett, & Glasson, 1991). Our observations showed that during the DNA experiment students were expressing a feeling of uncertainty and fear that they could not obtain a sample of DNA at the end of the investigation. Ms Claire, too, was concerned that her students might not spool a good sample of DNA:

Ms Claire: Girls. I'd like to say a couple of things about the ice-ethanol, supposing we are all at the stage...Girls, once you've filtered and got about 10ml, you transfer it to one of these clean specimen bottles that are in this tray here don't use the one that you put the salt in, come and get one from here...
Lydia: I put too much thickener, so it's not perfect, it's too thick. It has to be… (Dialogue over Ms Claire's voice.)
Ms Claire: …so put that in your filtrate, then the ice-cold ethanol is done by a bottle. You put it down flat on the desk, and then you very carefully pour the ethanol down the side, so that you're not actually mixing the two, so the ethanol sits on top. You leave it for 2-3 minutes, at the interface of the two liquids the onion filtrate and the ethanol, DNA should start to precipitate out, a yellowy/white substance, a bit like snot (laugh). You can come and get one of these little bent hooks. I want you to let it sit for 2 or 3 minutes, if you go in after this time, you can find a little strand and gently pull it out very slowly...and you have actually got bits of DNA on your little rod...

Andrea and Lydia then followed Ms Claire's instructions. They still expressed a feeling of uncertainty about the outcome of their experiment while other groups had already completed and were cleaning up:

Lydia: Maybe we should push it against the side of the tube (laughter)
Andrea: I think ours is right.
Lydia: Well we're not doing anything wrong (muffled pause) Keep going, just keep… is it supposed to be floppy like this?
Ms Claire: (Talking to other girls about cleaning up in the background.)
Andrea: Great.
(Long muffled pause.)
Andrea: I think there's…(Ms Claire talking in background, lots of noise during long pause.)
Lydia: That'll be enough, this is really gross.
Andrea: Is it?
Lydia: It is. (Pouring sound then tap running.)
Andrea: Ours isn't clear.
Lydia: It was clear until um…we put the...
(Everyone is cleaning up and it is very noisy.)

With some tolerance of uncertainty, Lydia and Andrea continued to monitor their procedure against their expected results. Then Ms Claire gave more instructions:

Ms Claire: Girls put all the extra onions on the tray, all the glasses…(background talking)…alright I think we've got some here, is everything sorting out
Lydia: Just got to put this away.
Andrea: Nah, I'll get it.
(Long muffled pause)
Lydia: You can usually just hook them out.
Andrea: Oh alright.

Episode 5: Observing the molecule of life

When most groups had obtained their results, a student from one group clarified with Ms Claire whether her sample was DNA in the following dialogue:

Student: Ours is yellow, not clear.
Ms Claire: That's OK; it'll all be alright, it's not completely clear. Clear doesn't mean no colour, it just means see through.

Ms Claire assured the student that what she had obtained was a correct sample of DNA though its colour was not clear. For other groups who did not obtain any results, Ms Claire showed them a good DNA sample from one group:

Ms Claire: Have any of you got some DNA precipitating out? Did you get some (name of a student)? So that's our DNA. (Laughter). Girls, when you've tidied up... Girls are you managing to get DNA from the cup?
Student: Can I have a look at it?
Ms Claire: Don't shake it up, OK. Keep it flat. The white stuff is DNA. (Pause.) (Students talking and laughing.)

Finally, Lydia and Andrea managed to obtain their results and they finally observed a sample of the molecule of life they had painstakingly extracted from the blended onion:

Chi-Yan: Do you see the DNA... jelly-like substance?
Andrea: Yeah (muffled pause)...Yeah I don't have my lab book at the moment.
Chi-Yan: Ok...see the instructions over there.
Andrea: Yep, I've got them.

Andrea again read the instructions to make sure that the jelly-like substance was DNA from the blended onion.

Episode 6: Follow-up discussions

At the end of the experiment, the teacher organised a whole-class discussion of the questions given in the manual (see Appendix 2). Given the tight time constraints, the discussion, which was largely teacher-dominated or a *teacher exposition* as Lemke puts it, was followed by a *triadic dialogue*. The first part of the discussion was centred on the procedure of the experiment and the second part touched on DNA as genetic information for life functions:

Ms Claire: Ok, girls I want everyone down here beside me. (Pause) I want everyone to remain quiet. Girls, stand over here, bring your worksheet with you 'cause there are a couple of questions you need to answer...
Students: Ewww (in chorus).
Ms Claire: Ok girls, ...basically we could have used any living thing and extracted DNA from it; we just chose an onion. We could have picked anything. Remember everything that is living is made up of cells, has a nucleus and has got chromosomes in it. So it's got DNA. There are a couple of questions that some of you have asked me as I've been wandering around to answer on your page; the first one was. Why do you think we blended the onion? What do you think the point of blending was in this experiment? What do you think it did to help to get the DNA extraction in the end? How is blending going to help that?
Student: I think maybe because when you added all the ingredients and stuff it might have broken it into smaller particles to get like a full result…
Ms Claire: So blending would have made it smaller…but what are onions made of?
Student: Cells.
Ms Claire: Cells, and what do you think the blending would have done to the cells? Broken them apart, OK. Release the contents of the cell. It's urgent girls. We've not really done much on the structure of the cell membrane, but it's actually quite fatty. It's got lots of fat molecules in it, and the detergent actually helps to break down the cell membrane, and the nuclear membrane. So all of the processes actually end up breaking down the cell wall, breaking down the membrane so that we are releasing the DNA. The meat tenderiser digests some protein molecules that are there but leaves the DNA infused...

After having discussed why they had followed the blending and tenderising procedure, the teacher touched briefly on DNA as genetic material. She explored DNA's relationship with chromosomes, which are cytological structures, and the information carried in DNA's genetic code for building the cells of an onion. The following *teacher exposition* potentially evoked the students' imagination and let their thinking move to a higher conceptual understanding of genes as DNA. This was to be followed by another *triadic dialogue,* as in normal lessons, about the location of DNA in prokaryotic bacteria:

Ms Claire: There are only two questions at the end that you have to answer. Why is DNA such an important component of cells? Why is DNA an important component? It's got the information, it makes chromosomes, and it carries the genetic code. Anything like that would be a correct answer. OK? Chromosomes are made of DNA, it's got the genetic code, and without it the onion couldn't build itself, could it? Cells wouldn't be able to function. And the second question, do you agree with the following statement? Explain. Bacteria don't have a nucleus so they don't have any DNA. Do we agree with that statement or disagree?
Student: Disagree.
Ms Claire: Why do we disagree? You have got to explain.
Student: Because bacteria has got most…(fades off).

Ms Claire: But any organism would need DNA because it needs the information to grow. You know from your (understanding of) prokaryotic cells that bacteria do have chromosomes; they just don't have a nucleus.

Andrea: A fruitful Learner with Power and Promise

If status is the hallmark of all conceptual learning (Hewson & Lemberger, 2000), Andrea's conceptual-change learning trajectory was a telling example. Andrea was interviewed three times during the study. In the first interview, she was unable to explain how DNA determines an organism's characteristics. This was not surprising because these ideas had not yet been taught by the teacher. In the last interview, although she did not mention the hands-on experience of seeing the real DNA she and Lydia extracted in the DNA experiment, she could confidently explain how mRNA transcribed the information from the DNA to bring about the synthesis of proteins for some particular functions. Using Thorley's (1990) status analysis categories, it was found that at the end of the unit on genetics and biotechnology, Andrea's conceptual understandings had a high status. Her conception of the gene was found to be intelligible, plausible and fruitful, displaying the power and promise about what she had learnt (Tsui & Treagust, in press).

Discussion and Conclusions

We have to consider again the key question in this paper. Is seeing believing? The notion of "seeing is believing" has been in use in science classroom for many years since the Nuffield schemes started in the UK in the 1970s (Gott & Duggan, 1995). However, such guided-discovery practicals beg the question of whether the time, energy and material resources used in such investigations are useful for helping student understanding of science. According to Hackling (2004), the experiment reported in this paper is just another recipe-style laboratory exercise in which students follow a procedure to investigate questions set by the teacher. In this case, students were to extract and observe the DNA in onion cells and understand the laboratory skills involved in the extraction. Despite this experiment being typically a guided-discovery investigation, we believe that actually observing the real DNA which students themselves extracted from familiar onions can be useful for developing a deeper understanding of the gene concept. From our classroom experience, observing real DNA is intrinsically motivating for Year 10 students. Ideally, however, such a hands-on activity has to be moved from hands-on learning to minds-on understanding.

Through our analysis and interpretation of the classroom discourse during the experiment, we found that students demonstrated a number of skills in manipulating the apparatus and justifications for the procedures followed. Based on the hints given in the laboratory manual and discussions with the teacher, students were required to answer questions at the end of the experiment and to think about why they had used particular procedural steps. They thought about the impact each of the steps might have had on their success or otherwise, of spooling the DNA for observation.

DNA, the molecule of life, is something most students should observe as a once-in-a-life-time, hands-on experience. The teacher did make an attempt at evoking in the students' imagination the profound idea that this snot-like matter of life that they were observing contains information in controlling life functions. We suggest that the teacher could have done more in this direction. In this way, teachers can possibly move the learning situation from a mere hands-on exploration to one with minds-on thinking and deeper understanding of the gene concept.

Ms Claire had already taught about the central dogma of DNA[3]. As a consequence, she could have connected the discussion of the DNA experiment to other parts of the teaching and learning activities the students had participated in. Ms Claire did engage her students in other gene technology activities such as:

- Facts on hereditary conditions, chromosome disorders and birth defects (done three weeks before the DNA experiment)
- Group presentations in class on human genetic disorders (done two weeks before)
- DNA fingerprinting (done on the previous day)
- Genetic engineering (done in a week later)

Year 10 students in Ocean School, who each owned a laptop computer, also had been engaged in interactive learning activities in the classroom using *BioLogica* (Concord Consortium, 2001) and online multimedia such as the *Your Genes Your Health* website (Cold Spring Harbor Laboratory, 2002). They also were taught about the story of Rosalind Franklin and her contribution to the construction of the DNA model. The teacher could have related her students' thinking in the follow-up discussion to some of these activities to engender deeper understanding of the gene concept and DNA as the molecule of life. By establishing relations of multiple representations of genetic knowledge, teachers can encourage students to construct deeper understanding such as reasoning (Tsui & Treagust, 2003a).

The twentieth century or "the century of the gene" (Keller, 2000, p. 1) started with the rediscovery of Mendel's classical paper and the birth of genetics. It took some fifty years to understand the molecular mechanism of genetics through Watson and Crick's DNA model and another fifty years to unravel the "the book of life" (von Baeyer, 2003, p. 42) — the human genome that records the totality of human genetic information. What will happen in the next fifty years? In 2003, James Watson, the first director of the Human Genome Project, told *Time*'s interviewer, "...We have more frontiers (for research in biology) now than when I was getting started. How the mind works, for example, is still a mystery..." (Lemonick, 2003, p. 46). Indeed, one key research area about the mind will be to validate the complexities of human consciousness by mapping the gene-expression patterns as each brain cell has a full set of genes in its DNA but only some of them are expressed at any given time into proteins affecting our thoughts, emotions and feelings (Bloom, 2002). DNA technology used in genomics[4] and proteomics[5] will continue to change biomedical sciences in the next fifty years. It is essential for science teachers to teach students about the gene concept in a way that is simple and captivating yet scientifically accurate.

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[3] It is the statement that genetic information flows from DNA to RNA to polypeptide or protein (in retroviruses, such as AIDS virus, there is also information flow from RNA to DNA) (Purves, Sadava, Orians, & Heller, 2004).
[4] The study of the entire set of genes in an organism and their interactions (based on Purves et al., 2004)
[5] The study of the total of different proteins that can be made from an organism's genome (based on Purves et al., 2004).

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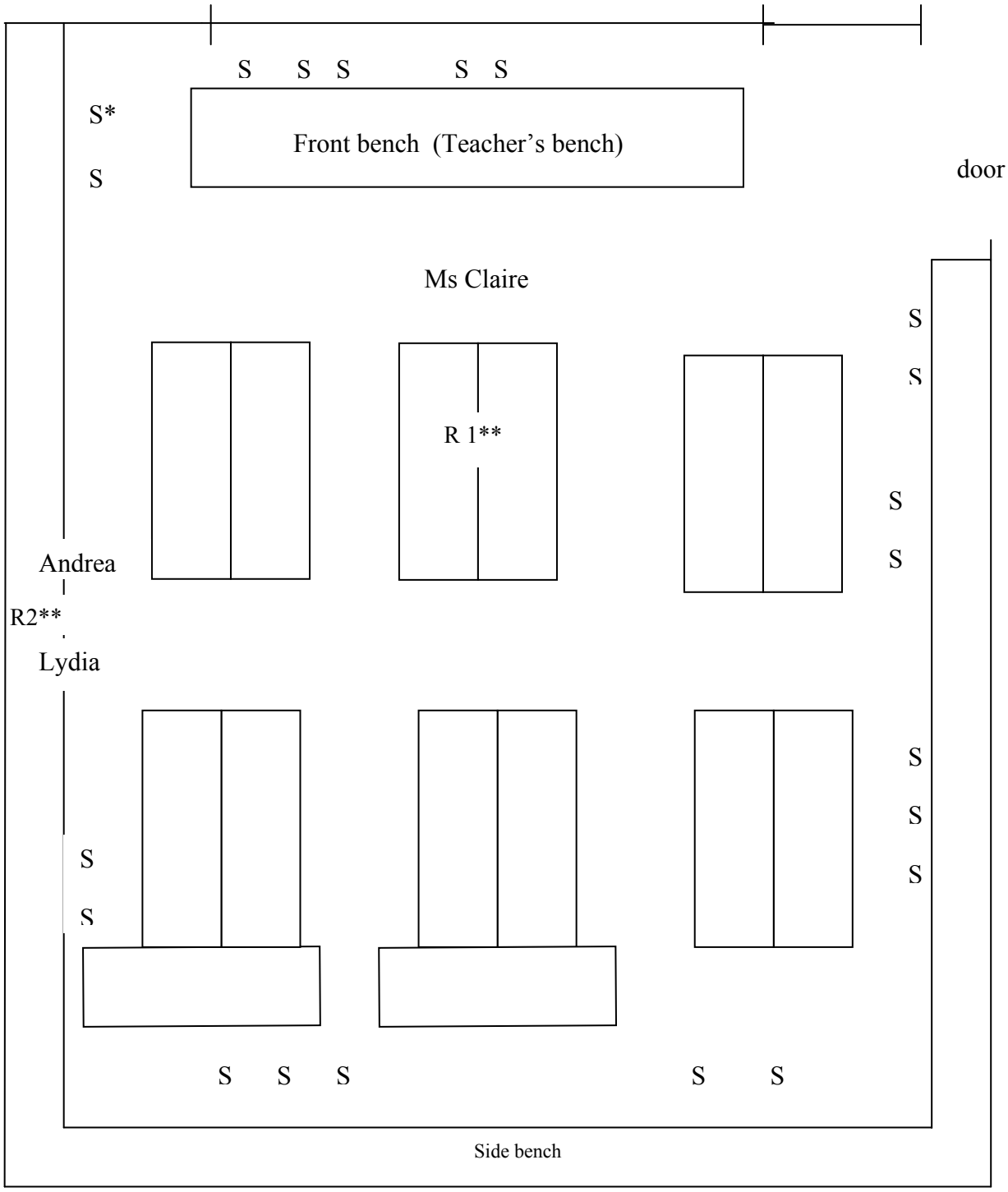
Appendix 1: Classroom plan during the DNA experiment (25 June 2002)



Note:
* S stands for a student in a group
** R1 and R2 are the positions of the tape-recorders

Appendix 2:
YEAR 10 BIOLOGY LABORATORY EXERCISE - Spooling of Onion DNA

INTRODUCTION

Most people think of DNA as an impossibly small molecule. After all, it is inside a cell too small to be seen without a microscope and is further compressed into a nucleus inside that cell. It is certainly not something that students normally expect to handle during a laboratory. However, this procedure is a quick and easy way to allow you to actually see some DNA from an organism with which you are familiar, an onion.

EQUIPMENT AND MATERIALS

Conical flask, 1 x 500ml beaker, ice cream container, thermometer, blended onion, funnel, chux cloth, meat tenderiser, 2g NaCI, 2 teaspoons Lux flakes, small specimen bottle, 10ml measuring cylinder, tripod, gauze mat, Bunsen burner, stirring rod. Collect only when required:- ice, 5m1 of ice-cold ethanol, pipette, fine glass rod with hook.

PROCEDURE

1. Place the blended onion in a 500ml beaker. Now add 2 teaspoons of Lux flakes and 2g of NaCl and stir well. How does blending help you extract the DNA?
2. Boil for 8 minutes, stirring gently. Read the following while you are heating your blended onion. The detergent causes the cell membrane to break down and emulsifies the lipids and proteins of the cell be disrupting the polar interactions that hold the cell membrane together. The detergent forms complexes with these lipids and proteins causing them to precipitate out of the solution. NaCl enables nucleic acids to precipitate out of an alcohol solution because, it . shields the negative phosphate end of DNA, causing them to come closer together and coalesce. The heat treatment softens the phospholipids in the cell membrane and denatures the DNA-ase enzymes which, if present, would cut the DNA into small fragments so that it would not spool.
3. Cool the onion mixture to 40°c by running cold tap water over the outside of the beaker for 2 minutes and then placing it in a ice water bath (use the ice cream container) until the required temperature is reached. Stir gently during the cooling process. Cooling the onion mixture slows down the breakdown of DNA.
4. Add 1(2 teaspoon of meat tenderiser and stir gently for 5 minutes.
5. Filter the mixture through a double thickness of Chux cloth in a filter funnel into a conical flask.
6. Dispense 10ml of the onion filtrate into the specimen bottle.
7. Add 10ml of ice-cold ethanol to the test tube, pouring slowly and carefully down the side of the test tube so that the ice-cold ethanol sits on top of the filtrate.
   * You might find it easier to add the ice-cold ethanol to the onion filtrate using the pipette provided.
8. Let it sit for 2-3 minutes. You should see the DNA precipitate out of solution near the boundary between the onion fIltrate and the ethanol.
9. Gently swirl the DNA using the narrow glass rod with a hook on the end that goes into the onion filtrate. Swirl the glass rod so the hook is in the onion filtrate just below the ethanol and gently lift it up through the ethanol. DNA should be on the glass rod near the hook. You could repeat this swirling action several times to accumulate a good amount of DNA. (DNA looks like a whitish mucus - the clearer it is, the less impurities you have).

Questions:
1. Why is DNA such an important component of cells?
2. Do you agree with the following statement? Explain. "Bacteria don't have a nucleus so they can't have any DNA".