Teaching and testing about the Nature of Science: problems in attempting to determine students' perceptions

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Contents

Abstract

This paper reports on a pilot study that used a paper and pencil test to explore the views of senior high school students about the nature of science. One group of the students who completed the test had, in the previous year, experienced a particular unit of work designed to illustrate for the students what it was like to 'work like a scientist'. The paper and pencil test was administered to the whole year level (Year 11) that comprised the particular class from the previous year (Year 10) with the intention

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of determining the impact the unit of work had on these students. This paper highlights then an interesting paper and pencil test as well as the difficulties encountered in conducting an apparently straight forward study.

Introduction

There are many views about the way in which science should be taught in schools and one ever present discussion deals with the place of laboratory work within the curriculum (Tamir, 1991; Hodson, 1990; Hofstein, 1988).

Some have suggested that laboratory activities offer students opportunities to work like scientists and the notion of high school science students 'working like scientists' has long been valued by various science educators. An alternative view is that laboratory work more often that not offers students an opportunity to verify the work of scientists as opposed to working like scientists. Relevant to both these views is that students may experience difficulty in abstracting from their school context to envisage their work as something other than school work, such that their understanding of doing science through laboratory work may be limited by the fact their experiences occur in the context of schooling.

Another (albeit less common) purpose for practical work is to help students learn about the way in which scientific knowledge is produced. Recent research into high school students' views about the nature of scientific enquiry (Driver, Leach, Miller and Scott 1996), reveals little evidence of students' consideration of the processes by which knowledge claims in science are made. A commonly held student view reported in Driver et al's study is that science knowledge is secure and reliable. Ways in which individual facts are checked or challenged within the scientific community before becoming accepted knowledge was not found to be part of these students' picture of the way science is carried out.

As one component of a longitudinal study exploring the relationship between science content and science process (Berry et al., 1999a), we examined how teachers' attempts to help students better understand the role of laboratory work as a way of illustrating how science knowledge is shared and validated (Hart et al, 1998). For us, this research was interesting in demonstrating the impact of teaching with this kind of purpose (the idea of illustrating how science knowledge is shared and validated) on students' ability

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to understand the practice of science.

Context of the study

As briefly noted above, this research was one aspect of a three-year longitudinal study exploring the relationship between science content and science process. Through this research we spoke with a number of science teachers and students about school science teaching and learning. At one school site (an all girls' Catholic College in which the data from this paper is drawn) we were fortunate to work with two science teachers who were continually evaluating and redefining their understanding of the relationship between their teaching and their students' learning. One of the teachers, Alice (pseudonym) taught year 9 and 10 science at the school, while the other teacher, Susan (pseudonym) taught year 10 science and year 11 and 12 physics. The belief that there was a need to continually push students to learn about science in ways other than the stereotypical 'science as facts' was an important part of both of these teachers' thinking and classroom practice and certainly caught our attention as researchers.

Through their curriculum organisation and their teaching practice, it was clear to us as observers that Alice and Susan were attempting to help their students better understand science in ways that were perhaps not so common in other science classes with which we were familiar. For example, the science curriculum was modified so that more time could be spent exploring fewer concepts in a variety of ways, problem solving tasks were common so that students' science knowledge and skills would be called upon to interpret and solve science problems, and laboratory work was specifically designed to challenge the 'recipe' approach (eg. students simply following the laboratory procedure without thinking about what they are doing or why). As a part of this challenge to the recipe approach, Susan had designed a unit of work for her year 10 class specifically around the way in which knowledge claims in science are validated. In this unit, students were asked to select one experiment from a large selection of experiments, conduct the experiment, record their results and then document their approach in such a way that another group of students could duplicate their work. This procedure was an attempt to help students come to understand an important component of scientists' work and to illustrate that communicating results and having one's ideas re-tested by others is an integral part of developing, validating and accepting science knowledge (a full description of this process is available in Hart et al., 1998). One other feature of this unit was that (by coincidence) at this time

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Susan's student-teacher was himself a recent Doctoral graduate in Physics. In one lesson, he gave a presentation about his work and illustrated for Susan's students many aspects of science that were far from obvious to them. He explained the role of conference presentations and journal articles as well as the role of the science research community in developing and validating science knowledge claims.

As a result of the science teaching and learning apparent in this particular unit of work, but also because of the overall approach of both teachers, we were interested in exploring whether there was any lasting impact on the students' thinking about the practice of science. Our major focus was to follow up on the ways in which Susan's students were thinking about their science learning and to compare their thinking with that of other students who had not been taught the unit. Hence, attempting to 'explore' these students' understanding of the nature of science was enticing from the perspective of what we perceived as interesting approaches to science teaching. However, Susan's unit gave an extra impetus for exploring the influence of her particular teaching approach which we thought was thought provoking and different to that which we had observed in other schools at the time.

Method

Susan's unit was conducted in the second term of a four-term school year. In the following year (approximately one year after the unit had been taught) we developed a pencil and paper test (see Appendix) and administered it to all year 11 students at the school. The test attempted to place the students in a situation whereby the purpose of the unit and its impact on the students might be tracked across the whole year level to determine how students' understanding from Susan's former year 10 class compared with students who had not been involved in her unit.

The students from Susan's class (n = 28) along with the rest of the students at that same level (n = 65) were together given a 45 minute test. Part 1 of the test was a newspaper article (see Appendix) that we believed illustrated an interesting finding in a way not dissimilar to the intent of Susan's unit. This section of the paper, when completed was then collected and Part 2 was distributed for completion. The reason for the separation of the two sections of the paper was so that a student's initial response to the task could not be revisited and then altered by their understanding of their answers to the second section of the paper - which could have been used to

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inform their initial response.

From the total cohort (N = 93), we had anticipated reconnecting students' sections for analysis so that we could track those students from Susan's class (n = 28) and compare their results to the remainder of the year level.

Methodological problems

Unfortunately, not all students wrote their names on the papers (both sections), hence when we came to 'reconnect' the papers, Parts 1 and 2 did not always match and tracking the students became difficult. This therefore created a major methodological problem for us, as tracking for Susan's class now was not as straightforward as we had initially envisaged. Therefore, in an attempt to address this problem, two of the researchers analysed the papers for handwriting styles and colour (type) of pen/pencil used in completing the test. Eventually this allowed us to match up 87 of the papers while 6 were unable to be appropriately matched. Hence we were able to confidently see the overall views of the students with regard to the paper and pencil test. However, the major problem was that of the 28 students from Susan's class that we had hoped to track, only 9 papers were absolutely identifiable as coming from that cohort. We were therefore in the unenviable position of having interesting data on the whole year level's views of the nature of science through this pencil and paper test, but the strength of difference between Susan's class and the rest of the year level was not going to be strong.

Despite these difficulties, we decided to analyse the data. The findings which emerged we found to be very interesting, despite our methodological problems, and we therefore decided to fully analyse and communicate the findings to others as we thought a pilot study like this could be equally interesting for others involved in similar work. The pencil and paper test, we believed, to be a useful instrument for investigating students' views of the nature of science.

Each paper was numbered and the papers were divided between the four researchers. At an initial meeting, each researcher analysed 3 papers. We then discussed our approach to analysis to develop a consistent method for completing the task. After further discussion we constructed a proforma to document the results of the papers by question number. The analysis of the findings (which follows) illustrates these results in a sequential manner by moving through the paper question by question.

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Although we had initiated this project to see how Susan's unit influenced her students' thinking, the big picture of the process (i.e. all students' views), we believed, was still worth pursuing. We therefore offer the following analysis referring to Susan's class only where it is reasonable and helpful for exploring aspects of students' views that are of particular interest. Otherwise, it is the big picture (the overall student cohort views) that really matters most in this analysis.

Findings

Part One:

The first question on the test asked students whether or not they had completed any work in Year 10 science that examined issues in a similar way to the article which they had been given to read (see Appendix 1). We had hoped that those students from Susan's class would have seen the link between the article and their Year 10 science unit and responded positively to this question. However, the response to this question was not as straightforward as we had imagined.

From the 87 responses to question 1, 76 stated that they had not completed any work of this nature in science, and 11 stated that they had. Of the 11 who responded positively to the question, only two came from those that we could definitely attribute to being members of Susan's class (the class taught the particular unit of work which was the impetus for this study). Hence it was not possible to draw any conclusions about the nature of the unit and their views of science.

We were surprised that such a small number of students (11 students which is equivalent to 13%) identified that they had done work related to the ideas inherent in the article. We had expected that even students who had not completed the unit might have considered the fact that having done experiments during Year 10 that they may have linked with the scientists in the article doing an experiment as part of their research. On the other hand though, the low response rate should not be so surprising considering how consistently findings of this type are reported in the literature (for example Lazarowitz and Tamir, 1994). Therefore, this result is a reminder of the difference between researchers' expectations and intentions when personally involved in a study. The fact that we saw value in Susan's unit of work combined with our

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overall view of the teaching approach by both Susan and Alice created an expectation of impact on students' thinking despite our knowledge of the research literature. Further to this, within the 13% who noted a link, about half of those students saw content as the link between the article and their Year 10 science experiences. For example, they selected either "light" or "genetics" which they had studied in Year 10 as the link yet we were 'expecting' the link to be related to processes of science, not the content per se.

Of those that did see links in the way we had envisaged we were 'searching' for, two students offered answers related to aspects of scientific practice. The first student (Student 75), who had been in Susan's class noted,

> I suppose the main link would be that the scientist probably undertook a more advanced, yet similar process when doing the experiment [reported in the article]. When we did experiments, we had an aim, and analysed our results etc. etc. This would have been the basis of what those scientists did.

The other student (Student 78) had been in Susan's class as well. She commented on the Qualitative Analysis (chemistry) unit that Alice had taught in Year 9 as well as on her experiences in Year 10. She wrote,

> Qualitative analysis - they link because in both instances the experimentors [sic] try to find flaws in the experiments especially if the results of the experiment ere 'unexpected'. Also, in year 10 we conducted experiments that I learnt something from but as with the article - the results of one experiment is not solid proof - other scientists have to get the same result from the same experiment for the results to be considered factual (Also something I learnt in Year 10 science).

In both cases, it is clear that their school science experiences have enabled these students to recognise that the way in which experiments are conducted to validate claims is an important feature of science. Both students have applied this thinking to the article used in the test. Although this abstracting from one situation to another is obviously extremely low in frequency, it is important to note that it did occur and that their school science experiences have helped these two students to build some appreciation of the ways in which scientific knowledge is constructed. So developing a more holistic view of science - beyond "science as facts" - can happen! However, it

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is somewhat disappointing that the take-up rate by students is very low. To understand why more students did not respond in this way, we need to consider what the negative responses illustrate.

76 students (87% of the total cohort) did not see a link between the article and their Year 10 school science experiences. Of these, we noted that 28% (21 out of 76) specifically said that they did not remember doing any work that was like that described in the paper. For example, consider the following:

> I can't remember what we did in Year 10, but I don't think there were any topics which related to the article. In science we would always research for the answer instead of saying [in] a 'mysterious way'. (Student 19)
>
> No this had nothing to do with our Year 10 course for science. If it did I can't remember. (Student 60)

It is interesting to note that the remainder (72%) of those that could not see a link indicated that in Year 10 they had not studied content which was relevant to the article in the test. Again, this may well illustrate how the students used content as an organising principle in their thinking about science and recognition of what constitutes science. The following responses are indicative of those in which the student could not see a link between the article and their Year 10 school science experiences:

> In Year 10 we studied plants, animals and bacteria. The article doesn't link with anything in the Year 10 science we also studied human development. (Student 64)
>
> No because Year 10 science was mainly about gravitation and forces and plant and animal cells, not anything to do with the biological clock in the human brain. (Student 43)

This framing (Schon, 1983, 1987) for linking we consider to be a most important issue as it may influence how the students begin to make sense of the relationship between their school science experiences and their developing understanding of science practice. Student 41 pushed this point further in her comment,

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> The article does not link with Year 10 science because we first had to plan our experiments and predict our results before presenting theories on how we obtained our results. The experiment would then be conducted as the last step towards the particular research. (student 41)

Again, her framing of the situation governed what she saw as a link between her school science experiences and this particular article. In essence, she compared her school experience of scientific practice with what she saw in the article, and rejected a link because the process suggested in the article did not map on to her learned experience from her school science. Interestingly, this (student 41) response highlights the staged, verification mode that practical activities normally represent. This student was not in Susan's class, although there were responses similar to this from students in Susan's class.

For us, the most telling factor about these students' responses is that the way students' portrayed their understanding of the nature of science in this test seems to be affected by the way they organise their memories of school science. For most students, content was the organising principle and this directed their linking of school science experiences to other science experiences. Unfortunately, because of the methodological issues it was not possible to determine whether there was any influence as a result of Susan's unit, however, it seems unlikely from the overall results. Another interesting result to us considering our 'expectations'! However, perhaps this result is interesting in another sense for the question was sufficiently open to allow students to respond in ways that drew on their initial views of construction of memory, therefore if content is their way into school science, it is something to be careful considered in constructing meaningful learning activities in school science.

Part Two:

Question 1 of this section of the test asked student to consider why the scientists' finding was "so surprising". Responses to this question that were of interest to us were those we considered illustrated an insight into the practice of science. This was not such an easy question to answer. Many students, rather than examining the surprising nature of the result either treated the question as an exercise in comprehension or expressed their disbelief at the peculiar link between light, the back of the knee and jet lag. Typical responses of this nature included,

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> Because it is very unlikely that a light on your knee will stop jet lag and insomnia. (Student 72)

> This was surprising to find out because it would be unlikely to happen. (Student 1).

We noted 14 (16%) responses that pushed beyond this idea of disbelief and began to focus on the findings and how the findings might be tested or questioned. For example,

> I think it's surprising because only your eyes can detect things like light. How can knees see light? (Student 74)

> I would say that the findings were so surprising because it goes against the scientific conclusions that have previously been made. It also opens up a Pandor[a]'s Box of other possibilities. (Student 75)

> Because they withheld judgement and it was an important issue that arised [sic]. (Student 64)

> Because you would never think, but simply shining a light on a knee would result in this stopping or resetting of the biological clocks. Also, it was not known that light could absorb/effect into the knee. (Student 69)

Question 1b followed by asking if experts often react to new discoveries in this way (ie by being surprised). Of the 76% of students who answered Yes to this question, 23% (15 out of 66) offered good reasons to accompany their response. Typical good reasoning was similar to that of Student 79 who wrote,

> I believe that they have to react like this as part of their profession. Without the discovery going through a series of proofs it would be misleading for the public if they confirmed discoveries and it would also be unprofessional as not all possibilities have been considered.

Question 2a asked the students to consider in the article *what was intended* by the

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expression, "if the findings hold up". We were interested in determining how many students attributed the meaning of this to the reproducibility of experimental results. 48% of the students responded in a way that suggested their recognition of this meaning.

In Question 2b students were asked to explain *how* scientists might see, "if the findings hold up". We analysed their responses in terms of the details of test reproducibility that they provided. 43% of students offered details that we thought indicated an understanding of how to test for reproduction of results.

Question 2c pursued these ideas further by asking the students, "if they had ever done anything" in their science classes that involved testing results (using 2b as the example). Interestingly, 44% of students responded positively to this question and offered examples from their school science experiences to support their answer.
One example is that of student 79 who wrote,

> Yes, when testing whether a substance was an acidic or basic solution we used both pH paper and universal solution comparing our results we collected information from a range of sources before making the conclusion that the solution was an acid or a base.

As we discussed above, the initial finding from Part 1 was that the students did not explicitly link the article to their Year 10 science experiences. In fact, the open-endedness of part 1 also carries the problem that the students may well have been attempting to second-guess what was required. Despite this, there are clear signs in the data for Question 2c that they have in fact made links with the process of scientific verification outlined in the article and the processes in which they have engaged in their science classes. One possible reason for the difference in the data for Part 1 and Question 2c is that the latter was preceded by other questions that acted as prompts for students' memories. Another is that the wording of Part 1 specifically refers to Year 10 science experiences. This is because our original intention was to explore and compare the effects of doing Susan's unit in Year 10 on students' understanding of science practice. As students answered this question, and given their tendency which we have discussed to consider linking in terms of content, their focus may have been on trying to decide when they did whatever content they remembered as opposed to their learning experiences.

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Question 3a attempted to explore the students' understanding of a scientist's statement in the article concerning their attempts to find flaws in the experiment. Only 8% (7 out of 87) gave well-expressed responses that indicated a clear understanding. An example is the following:

> They were trying to find out if the results just happened by chance or if they were incorrect when experimenting. (Student 75)

Question 3b was designed to uncover how the students thought testing for experimental flaws might occur. 47% of the students responded to question 3b by noting the need for experiments to be reproducible and 41% mentioned aspects of experimental design and conditions associated with experimental design that were important to test for flaws.

> By testing it on different people who have different sleeping patterns. (Student 86)

> By doing more tests on different types of people. (Student 4).

> They probably looked over everything, tested it over and over again. (Student 2)

> By testing different people - old, young, as well as using different lights like torches and dim lights. (Student 55)

> By doing really close examinations on all the people being tested ie. To make sure some weren't less tired than others, what they had eaten (in case they had more energy). (Student 43)

Question 4 was concerned with exploring the students' understanding of communicating results and asked them to consider why the article might be published in the journal Science as well as a newspaper (in this case one of the daily papers The AGE). 66% of students responded in terms of the need to publish for an appropriate audience, hence the need for an article in Science, and 32% noted the need to generally communicate results as an important reason for the different forms of publication.

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> So that people only interested in the SCIENCE field read about the experiment. (Student 14)

> It would be published in Science so that people would take these findings seriously. (Student 26)

> Because it is an experiment [in] which no flaws have been found and so is liable to be published to inform scientists and people. (Student 25)

> People who are interested in science could see the findings. (Student 33)

Question 5b attempted to probe the students' understanding of the purpose of scientific inquiry and asked the students whether they thought that scientists generally approach experiments with some idea of what they are attempting to investigate. 87% of students responded positively to the question with 62% noting that such an approach was self-evident.

> They have to know where they are headed but also they could discover stuff they did not know. (Student 85)

> Because they would waste their time and money if they didn't have an idea in [sic] what to do. (Student 22)

> Because they nearly always know what they're doing. (Student 14)

> Yes because why would they choose to do this experiment. Sometimes these findings can be found by accident. (Student 39).

Interestingly, only 8% of students (7 out of 87) noted a relationship between the experimental method and the idea being tested. For example,

> They have to have an idea of what they are trying to find in order to construct an experiment procedure in the first place. (Student 78).

> Before conducting an experiment a[n] hypothesis need to be developed. They

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need an aim to prove or to disprove an idea. (Student 25).

Conclusion

As we have noted, we were unable to follow our original plan that was to explore the responses of the students who had been in Susan's class in Year 10 the year before where they had done a unit that focussed on aspects of the practice of science. However, we suggest that the responses from the total cohort provide food for thought about teaching and testing about scientific practice and the instrument developed offers ways of doing this.

We believe it is reasonable to suggest that the results of Part 2 indicate that just under a half of all the students had a reasonable understanding of the conditions under which experimental results come to be accepted by scientists. In other words, just under half of the year level cohort had a concept of science that extended beyond science as facts and included some notion of the practice of science. Yet in Part 1 when the students were asked to think about links between an article that reported a scientific finding and their Year 10 science experiences, most students considered the possibility from the point of view of content rather than process. This raises the question, "Does this mean that the way students remember school science experiences and interpret information to do with science is largely on the basis of content?" We would argue that the way science is organised and presented to students, and assessed (according to content topics), may well provide implicit messages that remembering content is what is valued and indeed that content determines the nature of the subject. As all the students in the cohort we tested had had experiences that had encouraged them to think about the way science knowledge is developed, it would seem that this message about content is a powerful one. Further to this, the need to make explicit features of the nature of science seems to be a most important aspect of science teaching that is far too easily overlooked and, by not making it explicit, perhaps encourages alternative perspectives such as the content centred conception.

As well as raising questions about the teaching of science, these findings also have implications for researchers, such as us, wishing to explore students' perceptions of science practice and science learning. In the first part of the test, which we deliberately left open ended to elicit students' true reaction, they framed their

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responses according to content and, as noted earlier, perhaps sought to second-guess what they thought might be expected of them. Hence, it is well to remember how the nature of the task shapes students' responses. In the second part, where we signalled the aspects of science of interest to us, students responded in ways that indicated their understanding of our intention. Consequently, the responses elicited may not in fact be complete representations of what students really think.

We have been reminded through this process how probing students' perceptions of their science experiences is indeed a complex task and how easy it can be to overlook or forget such a point when exploring the influence of science teaching on students' learning. As researchers, we had clear views about that which we sought to gain data about and our expectations were influential in shaping both our method and our understanding of the situation. Importantly though, the process we report here illustrates how we sometimes fail to see that which we carry as taken-for-granted assumptions about teaching, learning and researching teaching and learning and it is helpful to be reminded about this. Finally, despite the methodological issues that arose, the overall pencil and paper test offers insights into these students' views about the nature of science and is a reminder of the constant need to seek rather than assume, understanding of students' perspective.

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Appendix

Extract from The Age 1711/98

New clue to insomnia and jet lag

Biological timer ticks behind knees

Sandra Blakeslee

NEW YORK, Friday

In an experiment from the strange but possibly true category, scientists have shone a bright light on the backs of human knees and, in some mysterious way, reset the master biological clock in the human brain.

Those treated with the light had their biological clocks advanced or delayed up to three hours, enough to overcome the fatigue associated with familiar forms of jet lag or insomnia. Why shining light on the knee would have this effect is a mystery.

The finding is so surprising that many experts said they were withholding judgment until the experiment was done again. But those who heard the study described at a meeting last year said it was carefully done.

1.

"We were all flabbergasted," said Dr Michael Menaker, a biologist at the University of Virginia in Charlottesville. "For three days we tried to find flaws in the experiment and we couldn't."

3.

Dr AI Lewy, an expert on circadian rhythms at the University of Oregon Health Sciences University in Portland, said: "<u>We have taken it as received wisdom that such effects would have to be mediated through the eyes</u>. 1 am very surprised. It is so revolutionary."

This sentence means that it is generally believed that only the eyes can detect light.

Dr Thomas Welir, chief of the clinical psychobiology branch at the National Institute of Mental Health in Bethesda, Maryland, said: "There are more biological mechanisms underlying the human response to light than was dreamt of in our original hypothesis. Still, until others repeat the experiment. The findings have to be regarded as preliminary."

5.

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2. If the finding holds up, the experts say it will have profound implications for basic biology overturning conventional ideas of how biological clocks are set.

It may also lead to new treatments for seasonal depression sleep disorders and jet lag. Airline passengers could wear a knee brace with a light source that would reset their biological clocks as they slept during the flight.

4. The study which is being published today in the journal *Science*, was done by Dr Scott Campbell and Dr Patricia Murphy of the Laboratory of Human Chronobiology at Comell University Medical College in White Plains, New York. -New York Times

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Questionnaire Part 1:
Name:

Part 1: Please read the article on the back of this page about the results of some scientific research.

(a) Can you link anything in this article about how this scientific research was done with any of your experiences in Year 10 Science? Yes or No.

(b) If you answered Yes, please indicate what the Year 10 Science experiences were and how they link.

If you answered No, please indicate why the article do not link with your Year 10 science experiences.

Questionaire Part 2:
Name:

Part 2: Now we would like you to comment on some specific things from the newspaper article.

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Question 1: Read the sentence labelled 1:
(a) Why do you think the finding was "so surprising"?

(b) Do you think experts often react like this to new discoveries? YES/NO
Why do you think so?

Question 2: Read the sentence labelled 2:
(a) What do you think "if the findings hold up" means?

(b) How do you think scientists will go about seeing "if the findings hold up"?

(c) Have you ever done anything like (b) in any or your science classes? YES/NO
If yes, please briefly tell us about it.

Question 3: Read the sentence labelled 3:
(a) Explain in your own words what this sentence means (NB: "flaws" means "mistakes").

(b) How do you think scientists would have tried to find flaws in the experiment?

Question 4: Read the sentence labelled 4:
This article was printed in The AGE newspaper and many others around the world. Why then would it also be published in the journal Science? (NB: "journal" means "magazine")

Question 5: Read the sentence labelled 5:
This seems to suggest that the scientists who did the research had some sort of ideas about the research before they started.
(a) What ideas do you think these scientists might have had?

(b) Do scientists usually have ideas before they start an experiment? YES/NO
Why do you say this?

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