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ABSTRACT

The substantial interest exhibited in the last decade in the identification of students' misconceptions of a wide range of scientific concepts has not extended to identification of students' misconceptions of the nature of science itself. This study examined the attitudes of 32 secondary school students, each from Canada, the United States, and Australia who had displayed a range of ability and interest in science. Students were administered a common set of interview questions, with provision to allow each individual to elaborate upon his or her responses. Analysis identified a number of conceptions that sometimes varied across countries. Results indicated that: (1) students held two vague views of the nature of science, an environmental view particularly favored by more than half of the Australian students, and a more general view of science in the everyday world; (2) science was mostly seen to be different from other areas of academic interest; (3) the mechanistic "scientific method" was evident in most American students' responses, in a third of the Canadian students' responses, and absent in the Australian Students' responses; (4) three quarters of the students believed that science changes, with some variation due to nationality; (5) more than half the students expressed the general belief that science is inductive; (6) students appeared convinced that scientific knowledge was factual, but became skeptical upon further questioning; (7) most students perceived theories as representing tentativeness; and (8) students say laws are confirmed facts or matured theories. Contains 14 references. (MDH)

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A MULTINATIONAL STUDY OF SECONDARY SCHOOL STUDENTS' VIEWS OF THE NATURE OF SCIENCE

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A MULTINATIONAL STUDY OF SECONDARY SCHOOL STUDENTS' VIEWS OF THE NATURE OF SCIENCE

ABSTRACT

The substantial interest exhibited in the last decade in the identification of students' misconceptions of a wide range of scientific concepts has not, with few exceptions, extended to identification of students' misconceptions of the nature of science itself. In the present study, 32 students, from each of Canada, the United States and Australia who had displayed a range of ability and interest in science, were administered a common set of interview .estions, with provision to allow each individual to elaborate upon his or her responses. A number of misconceptions were identified, which sometimes varied across countries.

INTRODUCTION

The last ten years or so has seen a massive effort on the part of science educators to uncover the different conceptions held by students of school age and sometimes beyond of a wide range of scientific concepts. The results of this effort have been illuminating, and at times quite sensational. The scope of this burgeoning literature is best illustrated by reference to a bibliography of this research published recently by Pfundt and Duit (1991). This bibliography contains reference to more than two thousand relevant studies, most conducted in the period 1985 to 1990. Very few of these studies relate to the nature of science itself.

It would be inaccurate to suggest that researchers have not been concerned to identify the status of students' understandings of the nature of science. Indeed, several well known written instruments, for example, TOUS (Cooley and Klopfer, 1961), SPI (Welch, 1966) and NOSS (Kimball, 1965) have been in use for a considerable time. However, these and the large number of similar instruments developed in dissertation and other small scale studies all suffer from the limitation that they attempt to determine the degree of mismatch between the subject's concept of science and that of the test developer. As such, they all suffer from what Munby (1982) declares to be the "doctrine of immaculate perception", that researchers incorrectly assume that their subjects necessarily read the same meaning into test item statements as do the developers of the test items.

A further problem with the use of written tests is that they limit the range of possible responses, and may miss substantial areas of individual understanding and misunderstanding, as well as conceptions which might just be different. Researchers in

the general area of student misconceptions, alternative conceptions, naive conceptions, etc. have tended to turn substantially to the use of individual interviews, for example, 'interviews about instances' (Osborne and Gilbert, 1980) and 'interviews about events' (Osborne and Cosgrove, 1983). A large number of reports of interview studies now exists. Virtually none of these relate to students' understanding of the nature of science. Exceptions include reports by George (1987), Aikenhead, Fleming and Ryan (1987) and Griffiths and Barry (1992). The study by George involved an extensive interview of one teenager. The report was fascinating but could not be considered representative. Aikenhead, Fleming and Ryan's study was quite opposite in that data were collected from a large sample, stratified to enhance validity. Although the purpose of this study was to produce a written objective instrument eventually, in the developmental stage students were interviewed to identify the thinking involved in their construction of free-response paragraphs. The ultimate instrument contained eight sets of written items, including one set which related to students' understanding of the nature of science. Items appear to have well established validity and reliability. However, many appear to be very wordy and may require choice from ten or more statements. The use of these items has the advantages conferred by an extensive development procedure, but the disadvantage of not being able to probe individual understandings remains. Griffiths and Barry (1992) report the results of an interview study conducted with 32 Canadian high school students, stratified according to interest in science and ability in science. Substantial attention was paid to establishing the reliability and validity of the interviewing and data reduction procedures. A considerable match was observed between the results of these last two

studies. The present study represents an extension of the Griffiths and Barry study to Australian and American students.

METHODOLOGY

A common procedure was followed in each country and in each school setting. In each country, 32 students were interviewed. Students were selected to yield as generalizable and representative a sample as possible. In each case, students were randomly selected from four pools. These pools were described as 'science oriented - high ability', 'science oriented - low ability', 'non-science oriented - high ability' and 'non-science oriented - low ability'. Because grading systems vary, the parameters of high ability and low ability were not the same across countries. In Canada and Australia, high ability was represented as having an overall academic average greater than 75 percent. In the United States this percentage was raised to 80 percent, to accord with the generally higher grading system there. Low ability was taken as less than the above percentages. Students were designated as 'science' students if they had taken or were currently taking two or more science courses designed for university entrance. The non-science designation was used for students who had taken or were taking no more than one science course designed for university bound students. Student ages ranged from 16 to 20 years. The mean age for Canadian students was 17.6 years, for Americans 16.9 years and for Australians was 16.5 years.

Each student was interviewed individually. There was no time limit, but typically interviews took about half an hour. Each student was asked the following

questions: "What is science?" "Is science different from other disciplines? If so, how?" "How do scientists get their information?" "Does science change?" "What is the role of observation in science?" "What is a scientific fact? Give an example." "What is a scientific theory? Give an example." "What is a scientific law? Give an example." Each of these questions was the foundation for further probes. It should be understood that the purpose of the questions asked was to determine students' beliefs and understandings, not merely to seek remembered dicta. Each interview was audio-recorded, transcribed and converted to a set of statements summarizing the views of the individual student in each case. In effect, for each student a conceptual inventory (Erickson, 1979) was produced. Examination of these conceptual inventories formed the basis of the discussion section, which follows shortly.

Although some researchers might argue that our concern should have been illumination rather than generalization, we hoped to provide both. Hence our attention to forming a representative sample. We were concerned about both validity and reliability. We cannot claim to have sampled national populations as our resources did not allow this. However, as the results will show, there were both commonalities and differences between the samples, which may allow some national comparisons. At the very least the international breadth of the total sample enabled us to tap the views of a broader range of students than would be likely in one country. Within each national sample, the breadth of student interests and abilities gives us faith that typical student views were tapped. Further, because a number of teachers were involved in each case, we do not believe the results to be an artifact of individual teacher style. With respect to reliability, the

reliability of interviewing procedures may be a problem, in that three different interviewers were involved. Examination of the transcripts, however, does not suggest the presence of any bias. Reliability of the translation of protocols to conceptual inventories was checked by asking independent experts to rate the reliability of this translation. In effect would they have made the same decisions? Agreement was in excess of 90 percent. In general, we believe the data to be acceptably valid and reliable. Examination of these data follows.

RESULTS

Introduction

This section contains the results obtained for each national sample, collectively and singly. Only major viewpoints are reported, except where some particular comment made by an individual student appears to be of particular interest. When major viewpoints are reported, the overall percentage of students holding each view is given, together with the percentage for each country. In order not to convey an unwarranted suggestion of precision, these percentages will be rounded up or down to the nearest five percent. Minority views will be reported in terms of numbers of students.

What is Science?

The responses to this question were often difficult to interpret. Frequently, these responses were vague, and further probing was unproductive. The most common kind of response, exhibited by 55% of the Australian students, 30% of the Canadians,

35% of the Americans, and 40% of the combined group, related to environmental interpretations of science. Examples included: *"The study of natural occurrences in our environment"; "The study of natural elements and forces"* and *"...Just knowledge about the environment."*

The only other very common interpretable response to this question provided a general view focusing on some other interpretation of the world around. Twenty percent of the Australians, 30 percent of the Canadians, 35% of the Americans, for a total of 30% of the combined group took this position. One student wrote: *"Science is the study of the way people live, the way forces occur in nature, and just trying to understand the unknown."* Another suggested science to be *"The process of experimenting and searching for knowledge; the study of truth,"* and another *"A way of explaining how things work."* A few students, five in total, held a particularly technological view and four were particularly concerned with school science. The only national focus which stood out was the greater emphasis of the Australian students on an environmental interpretation of science.

Is Science Different? If so, how?

The direct response to the question "Is science different?" was almost uniformly positive in each country. In each case, 85 percent of the students were quite positive that science is different. When pursued with the supplementary question "If so, how?" this commonality broke down both within and across national groups. Reasons varied so considerably that there was little point in attempting to classify them.

However, many were illuminative of the way high school students think about science, although a qualification is necessary here. What these students were really talking about was school science, not a perception of science as practiced professionally. Science was seen as more complex than other subjects, *"...like the study of it is different... there's more to be found out for one thing than other subjects."* Science was seen as almost dehumanized... *"Science is not to do with people. If people weren't on earth science would still go on."* Science was seen as different *"...because it deals with everyday things."* Science was seen as a subject which *"...does not deal a lot with human nature."* Disappointingly, one student commented that *"Science is not creative. Either you prove it or you can't."* Finally, providing a hopeful sign for constructivists, the view was expressed that *"In other classes information is given; in science, you are forced to come up with it yourself."* No national differences were observed.

How Do Scientists Get Information?

The answers to this question showed considerable national differences. The American students were very attracted to the traditional, if misguided, view of the practice of science as involving a relatively set sequence of events. For example, one American student answered *"They come up with a hypothesis and then experiment. They formulate a hypothesis, set up control groups and experimental groups. They know how they are the same and different. They draw conclusions from their data."* Three of the 32 American students began with trial and error, and three more with unguided observations, but 75 percent of the Americans clearly articulated an explicit version of

the traditional scientific method. Only about 30 percent of the Canadian students were attracted to such a view, although this may be due in part to a lack of clarity with respect to any particular view. In complete contrast to the American viewpoint, the Australian students, although making frequent reference to 'experiments', virtually never spoke in terms of the traditional scientific method. Two-thirds were attracted to 'experimenting', but this often seemed to begin *"...through trial and error," "trying different things until it comes out right,"* rather than a mechanistic approach to scientific investigation.

Does Science Change?

Seventy-five percent of the total sample expressed a belief in the changeable nature of science. However, again there were national differences. It was interesting that similar proportions of students (40 percent of the Australians, 35% of the Canadians and 30% of the Americans) cited changes in instrumentation and technology as the cause of change in science. Examples included: *"Yes, the technology changes, the methods used change", "Equipment becomes more advanced and results more accurate,"* and *"Science changes with different technologies."*

A second reason, the influence of new ideas, was particularly important to the Canadian students (40%), less so to the Australians (15%) and was not mentioned by the Americans. For example, *"Science changes through a different line of thinking"* and, in a Kuhnian vein, *"Science constantly changes as previously accepted information is discredited."*

The American sample was different from the others, in that a substantial proportion (60%) suggested that science does not change. This compared with only fifteen percent of the Australians and none of the Canadians. Closer examination suggests that the reason for this lies in the American students' preoccupation with the traditional scientific method, a preoccupation which was alluded to in a previous section. Thus, for these students *"The actual method stays the same as I learned in the fifth grade: hypothesis, control, experiment,"* and *"The fundamental basis of experimentation and observation stays the same,"* and, consequently *"The method may become quicker or easier because of technology, but the method stays the same."* It appears that the American students were thinking of science in terms of process rather than product in answering this question, and often in terms of a particular view of process, namely the traditional scientific method.

<u>What is the Role of Observation in Science</u>?

Eighty percent of the sample provided interpretable answers to this question. Of these, thirty percent expressed a belief in the importance of observing, but did not express a direction for the relationship between observations and theories. For example, *"Observation has a very big role in science,"* and *"Observation is the basis for knowing what's going on."* Forty-five percent took the inductive position that theories are observation driven, through comments like *"You do an experiment and you observe... if you didn't observe what was happening you wouldn't have anything to start with. Observation comes before theory because to look at theory you need to have some sort of*

observation," Sixty percent of the Australians whose responses were interpretable, 45 percent of the Canadians and 25 percent of the Americans held to the position that observations come before theories.

The contrary deductive view, that observations are made under the influence of existing and proposed theoretical structures, was held by 35 percent of the Canadians, 25 percent of the Australians and 15 percent of the Americans. For example, one student commented that *"Experiments are based on theories and to see if observations match up with theory."* Another student, in response to the question "Which comes first, observations or theories?", had no doubt *"Theories, I'm sure."* Interestingly, 60 percent of the American students who provided interpretable responses indicated the importance of observation, for example, that *"It plays a key role,"* and, for another student *"Probably the largest role,"* but did not express an opinion of the direction of the relationship between observation and theory.

<u>What is a Scientific Fact</u>?

As well as attempting to determine students' understanding of this term, we were also interested in following this with questions designed to elicit students' beliefs in the status of factual knowledge. For example, "What makes a selected fact scientific?" and "Are scientific facts open to question?"

Initial responses were often very definite, although good examples of scientific facts were few. Many initial responses could be summarized as a fact is a fact; once established, it is unchangeable. For example, *"A fact is something proven. It*

cannot change," and *"It is a true event, like the North Star is there"* and *"A fact can be proven scientifically; if it changes, it isn't a fact."* Yet, upon further questioning such certainty began to break down: *"It can't change; its always the same; its a fact. It's a fact for that period of time."* Yet, later *"It could change later."* Another student said *"A fact is 100% true,"* yet, later *"It could be changed if someone comes along with a different way of testing it,"* and *"A fact is indisputable, 100% correct,"* yet *"...open to question because there is always a possibility that something may be researched further."* Examples of facts included Boyle's law, Darwin's theory of evolution, the 'fact' that hydrogen and helium are different because they have a different number of protons, and *"gravity, because it is a proven theory."* The words 'prove' and 'true' were frequently invoked. Although initially most students defined a fact in terms of truth ultimately, upon further questioning, 75 percent of the total sample including 85 percent of the Canadians, 70 percent of the Americans and 60 percent of the Australians indicated a belief, sometimes reluctantly, that a fact can change, and hence that factual scientific knowledge is tentative. The remainder were convinced of the certainty of factual knowledge.

What is a Scientific Theory?

The general response to this question showed widespread understanding of the tentative nature of scientific theories, although this may just represent a general interpretation of the word 'theory' in everyday life. Consequently, there were no substantial national differences.

Not surprisingly, students tend to see theories as smaller entities than do scientists. Although the word hypothesis was seldom used, it may be that students are really thinking in terms of singular hypotheses when they use the word 'theory'. There are, perhaps, two progressions which may be observed in these students' responses. The first is from idea to educated guess to theory (perhaps really hypothesis). The second is from theory to fact to law. Let us illustrate with some examples. Seven students, about eight percent of the overall group, described a theory as an idea. For example, *"An idea that hasn't yet been proved,"* and *"...like a person's thought... someone's idea"* and, more eloquently *"An idea; not concrete; a philosophy. A theory is a stepping stone. A theory is a cloudy idea, whereas a fact is concrete. Theory can change."* Almost 15 percent of the combined sample described a theory as an educated guess, for example *"Some kind of guess... you're pretty sure but not exactly,"* and *"A theory is a pretty sure guess,"* and *"A theory is not proven; it's an educated guess."* Finally, almost 80 percent of the students (85% of the Canadians, 85% of the Americans and 65% of the Australians) described theories as being tentative, yet more than a guess. For example, *"Theories help us get to a higher level of thinking; you can prove a fact, but you can't prove a theory. Theories change all the time,"* and *"...widely accepted as solved but they can't prove it,"* and *"Theories haven't been proven; but they are leaning on being proven; a theory could change."*

In recent years science teachers have frequently been exposed to the ideas of Thomas Kuhn and Karl Popper. Although rare, in a few instances it was possible to discern a Kuhnian or a Popperian view of science. For example, in line with Popper,

one student responded that a theory is *"Something that is unable to be proven conclusively, but is able to be disproven,"* and added that *"A fact is proven. A theory can be disproven but it has not yet been disproven."* Reminiscent of Kuhn (1970), another student commented *"Scientists have movements like artists. They each have their force and findings."*

The second progression noted above was from theory to fact to law. The parallel trend from uncertainty to reasonable certainty to overwhelming certainty was evident throughout and will be raised again in the next section. In the context of this section, the following student comments are illustrative: One student described a theory as *"Something not yet fully proven. After it has been tested over and over again then the theory will become stronger until it becomes law or fact."* Another student responded *"A theory is something we aren't sure of. When we are sure, its a fact."* For another *"Theories can be proven true and become facts."*

Some students tended to view the relationship in the opposite direction, namely that *"A combination of facts make a theory"* and *"A theory comes from facts,"* but generally students felt that the order of progression was from theories to facts to laws. Finally, we note that despite students' generally strong views about the nature of theories few could give acceptable examples.

What is a Scientific Law?

Not surprisingly, given the tenor of our previous remarks, we found that the students almost unanimously considered laws to be the most certain kind of scientific

information. Despite this, there seemed to be some differences in how they conceived of laws.

In a sense the 'power of the law' as something that can't be broken was most evident in the responses of the American students. Forty-five percent of their responses fell into this category, compared to 16 percent of the Australians and 20 percent of the Canadians. Typical comments were *"A law won't change. A theory can be changed; it would be much harder to accept a change of a fact or a law."* and, even more definitely, *"A law is constant; won't change. Theory could change, but laws are definite."* This certainty, for the Canadian students especially, caused an almost mandated legal authority. For example *"Laws are definite, can't change; they guide us in everyday life just like government laws,"* and *"A law is known to be true; we have laws in science to keep people from doing bad things,"* even to a common everyday analogy *"like driving within the speed limit on a highway."* Such legal metaphors were almost completely absent in the American students, with only two such responses, and were completely absent in the Australian responses.

Many students did not distinguish between laws and facts. Fifteen percent of the sample (24% of the Australians, 15% of the Canadians and 10% of the Americans) directly equated facts and laws. *"A law is accepted like a fact; there isn't much difference,"* and *"A law is like a fact; it won't change. A law and a fact are basically the same thing."* Twenty percent of the overall sample, including 35% of the Canadians, and 15% each of the Americans and Australians went even further, and considered a law to be a proven fact. For example, *"A law is a proven fact. You can say this will definitely*

happen... you definitely know what the outcome will be," and *"A law is basically a fact which has been thoroughly proved."* In effect, laws appear to represent ultimate truth *"A law is something that does happen. It's true."*

The most common representation of laws was to characterize them as mature theories, a finding which is consistent with earlier work reported by Rubba, Horner and Smith (1981). Forty percent of the Australians, 30 percent of the Canadians and 20 percent of the Americans exhibited this view. Typical responses were *"First there are theories, and then they are proven enough to become laws,"* and *"A law is a proven theory. Scientists use laws to create other theories."* Some were explicit about the relationship between theories, facts and laws, as in the following comment *"Someone has a theory and the theory gets worked on and expanded and becomes a fact, so people know it's true. And then the fact may some day become a law."*

Finally, in our discussion of students' understanding of the term law, we note that not everyone was convinced of the sanctity of laws. Five students, four Americans and one Australian indicated a belief that laws can change. For example, *"A law won't change, unless proven wrong"* and *"A law is concrete like a fact, not intangible like a theory; it can't change unless something changes to change it."*

DISCUSSION

We have indicated the views of 96 high school students, 32 each from Australia, Canada and the United States. Collectively, the responses of these students reveal a fascinating array of beliefs about science and its facts, laws and theories. The

design of the study was limited by practical considerations. It would have been attractive for each researcher to interview an equal number of students in each country. This was true in Australia only. However, some sense of reliability is gained by the fact that for each researcher the results were reasonably similar in the common country Australia, suggesting that any differences between countries are not an artifact of interviewer style. Within each country, at least eight different teachers were used and students were randomly selected from within four different groups representing a range of abilities and interest in science. The reduction of data from transcripts to conceptual inventories was monitored by independent evaluation by practicing science teachers. High agreement, in excess of 90% was observed. The questions themselves were derived from Griffiths and Barry (1992), who content-validated them by reference to a group of practicing science educators. Finally, we note that percentages are given to emphasize the prevalence of students' ideas. However, the sample is small enough that we suggest that these percentages should be considered illustrative rather than demonstrative. With these caveats, we turn to a summary and discussion of the data:

1. Students presented two relatively vague views of the nature of science, an environmental view particularly favored by more than half of the Australian students, and a more general view of science in the everyday world.
2. Science was almost uniformly seen to be different from other areas of academic interest, but in a multiplicity of ways which showed no national bias.
3. The mechanistic 'traditional' scientific method was very evident in the responses of the American students, evident in the responses of almost a third of the Canadians,

and absent in the Australian sample. These differences are considerable enough to warrant further investigation.

4. The question of whether science changes also yielded some apparent national differences. For more than three quarters of the sample, the simple answer was that it does. About half of these, without national bias, indicated changes in instrumentation and technology to be the reason for this. However, almost half of the Canadians were attracted to a different reason, which in effect seemed to centre around the importance of new ideas, and a revolutionary view of science. Neither the Australians nor the Americans had much to say about this. We do not know the reason for this difference, and again we urge caution in interpretation of data based on limited sample selection. However, several years ago, a major Canadian report on science education in Canadian schools (Science Council of Canada, 1984) urged that greater attention be placed on an understanding of the nature of science in school science. The report was widely circulated. We note also a substantial and long-term emphasis on this topic in the teacher education programme followed by teachers in the locality of the Canadian schools involved.

   The American sample was also anomalous in that more than half of its members appeared to think that science does not change. Further analysis showed that they were typically referring to methods not products, and again the influence of the traditional scientific method appeared to be very strong.

5. Is science inductive or deductive? The former view was slightly more prevalent, being held by more than half the sample, especially the Australians.

There was general agreement of the importance of observation in science, but a split on the issue of whether scientific theory is observation-driven, that is inductive, or whether observation is theory-driven, which would represent a deductive view. There was also an interesting national difference, in that whereas eighty percent of both the Australians and Canadians tended to take either an inductive or a deductive view, the majority of the Americans agreed that observation is important but were not concerned about the direction of its relationship with theory.

6. With respect to factual knowledge, most students appeared to be convinced of the certainty of such knowledge. However, upon further questioning this certainty was replaced by a healthy skepticism by about three quarters of the sample, with little national bias.

7. Most students appeared to hold an everyday non-scientific conception of the word theory as representing tentativeness, and their 'theories' appeared to represent hypotheses rather than theories. About 15 percent of the sample considered a theory to be an educated guess. About 80 percent considered theories to be more than this, as tentative but not a guess. Theories were often viewed as immature laws. There were no major national differences.

8. Laws were commonly seen either as super-facts or as mature theories. As such they represented ultimate authority. For the Americans especially, scientific laws are not meant to be broken.

We have described the operation and results of an interview study of high school students' understanding of a number of general terms used to classify scientific

knowledge. The study was conducted in three countries. More importantly, we have described students' beliefs in the underlying status of this knowledge, and how it seems to be similar and different in three different national settings. The results of the study are potentially useful to a wide range of science educators and curriculum developers, in that the usefulness of an education in science is restricted when its foundation is not understood.

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