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AN ANALYSIS OF FOUR WAYS OF ASSESSING STUDENT BELIEFS ABOUT STS TOPICS*

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Abstract

The study investigated the degree of ambiguity harbored by four different response modes used to monitor student beliefs about science-technology-society topics: Likert-type, written paragraph, semistructured interview, and empirically developed multiple choice. The study also explored the sources of those beliefs. Grade-12 students in a Canadian urban setting responded, in each of the four modes, to statements from *Views on Science-Technology-Society*. It was discovered that TV had far more influence on what students believed about science and its social, technological context than did numerous science courses. The challenge to science educators is to use the media effectively in combating naive views about science. Regarding ambiguity in student assessment, the Likert-type responses were the most inaccurate, offering only a guess at student beliefs. Such guesswork calls into question the use of Likert-type standardized tests that claim to assess student views about science. Student paragraph responses contained significant ambiguities in about 50% of the cases. The empirically developed multiple choices, however, reduced the ambiguity to the 20% level. Predictably, the semistructured interview was the least ambiguous of all four response modes, but it required the most time to administer. These findings encourage researchers to develop instruments grounded in the empirical data of student viewpoints, rather than relying solely on instruments structured by the philosophical stances of science educators.

Introduction

Over the past 25 years standardized instruments have been developed to quantify, and therefore assess, student understanding of science in its epistemological

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and social context [encompassed by the phrase "science-technology-society" (STS)]: *Test on Understanding Science* (Cooley & Klopfer, 1961), *Nature of Science Scale* (Kimball, 1965), *Science Process Inventory* (Welch, 1966), *Test of the Social Aspects of Science* (Korth, 1968), *Nature of Scientific Knowledge Scale* (Rubba, 1976), and the National Assessment of Educational Progress (Bybee, Harms, Ward & Yager, 1980; Hueftle, Rakow & Welch, 1983). These Likert-type and multiple-choice instruments have provided empirical data for researchers and survey data for policy makers and curriculum developers.

The instruments, however, suffer from a critical flaw. They all assume that both the student and the assessor perceive the *same* meaning in the items. This assumption of similar perception—"the doctrine of immaculate perception" (Munby, 1982)—came under scrutiny in a recent study. In conjunction with the International Association for the Evaluation of Educational Assessment (IEA) science study, Aikenhead, Fleming, and Ryan (1987) analyzed Likert-type and written-paragraph responses from 10,800 graduating high-school students. The students were asked to react to a statement concerning a STS topic by (a) stating whether they agreed with the statement, disagreed, or couldn't tell, and (b) writing a paragraph explaining the reasons for the choice. The students had responded to *Views on Science-Technology-Society* (VOSTS) form CDN-2, comprising statements based on major topics found in the epistemology and sociology of science literature (Aikenhead, Fleming & Ryan, 1987). One finding of the study was that student viewpoints on STS topics were not accurately captured by a Likert-type response format. These results were recently replicated by Brunkhorst (1987).

The problem with Likert-type responses is also shared by multiple-choice items. Yarroch (1986) discovered a consistent and significant overestimation of student understanding of biological ideas when students were evaluated by a standardized multiple-choice test. Their choices on the test did not necessarily reflect their understanding of biology, an understanding which evaluators thought was being expressed. Measures of science attitude have also created instances in which evaluators misread student responses. Schibeci (1986) detected that students reacted in an unpredicted way to an attitude instrument about scientists. The measure of scientific attitude is particularly problematic in this way (Gardner, 1975; Munby, 1983).

In addition to documenting the problem with Likert-type responses, Aikenhead, Fleming, and Ryan (1987) recognized deficiencies in student paragraphs. Graduating high-school students were not necessarily the most articulate writers, and some failed to provide critical information in their paragraphs about STS topics. The "doctrine of immaculate perception" can apply to student writing as well.

Given the prominence of STS goals in science education (ASE, 1979; Bybee, 1985a; Hurd, 1986; NSTA, 1982; Science Council of Canada, 1984), the problem of accurately assessing student viewpoints becomes critical. Indeed, science teachers often point to student evaluation as a major obstacle to the implementation of STS content in their science classes.

The general purpose of this article is to augment our understanding of student learning and its assessment in the STS domain. Specifically, the study posed two questions:

(a) What sources (science texts, teachers, home, media, etc.) seem to inform the beliefs that Canadian grade-12 students hold?

(b) What information is gained, and what is lost, in each of four different modes of student response: Likert-type, written paragraph, semistructured interview, and empirically developed multiple choice?

The first question was answered by employing a semistructured interview technique. The second was investigated by comparing student responses to all four modes of assessment, and by analyzing the degree of ambiguity harbored by each type of response.

A number of investigations have yielded a rich data base by using the student interview method. By interviewing students, Renner, Abraham, and Birnie (1985) gained insight into physics students' perceptions of the exploration phase of the learning cycle. MacDonald and Bridgstock (1982) discovered through their interviews that university students' images of science were relatively mild and always qualified, a result in conflict with similar Likert-type studies of student perceptions of science. Fleming's (1985) carefully crafted interview schedule revealed in detail how students' views on a socioscientific issue varied with the degree of personal involvement they had with that issue, and that scientific "facts" rarely influenced their thinking. Also by using a semistructured interview, Yarroch (1986) uncovered evidence damaging to the content validity of a standardized biology test. Qualitative data that accrue from interviews can help to establish a firm base from which to evaluate the validity of quantitative measures (Howe, 1985).

Research Procedures

Sample

The sampling objective of this study was to duplicate, as much as possible, some demographic features of the IEA national sample (gender, age, and the number of science courses enrolled in). A local setting (a medium-sized prairie city) was chosen out of convenience for conducting the student interviews. Two high schools participated, with student populations of 400 and 800. A teacher in each school picked out a cross-section of grade-12 students based on grade-point averages. The paragraphs written by the students appeared to be typical when compared with the average of the 10,800 responses analyzed in the national study. 27 students participated in all phases of the study. Each student was interviewed on four different STS topics, resulting in a total of 108 interviews.

Inferences from these interviews must be made cautiously. One cannot generalize about how students think as they write their paragraphs. One can, however, gain insight into how some typical urban Canadian students might operate under similar circumstances.

Instruments

Views on Science-Technology-Society (VOSTS) form CDN-2 contains 22 items, most of which have paired statements, one expressing the opposite view from the other. In total there are 46 statements. They focus on 16 STS topics prominent in the epistemology and sociology of science literature. The instrument was originally developed for a national sample of grade-12 students *(N* = 10,800) among whom the 46 statements were randomly distributed, one per student (Aikenhead, Fleming & Ryan, 1987). Students reacted to a VOSTS statement (a) by choosing "agree," "disagree," or "can't tell;" and (b) by writing a short paragraph explaining the reasons for the choice.

The present investigation draws heavily upon certain results from this national study, particularly the "student positions" that were developed (Ryan, 1986). These comprise the "empirically developed, multiple-choice" mode of response used in the present study. Because of their importance to this study, their development in the national study is summarized by the following description.

For each VOSTS statement, about 236 student paragraphs were analyzed to discern common arguments, thereby identifying categories that represented students' common viewpoints or beliefs. These categories became "student positions." In other words, for each VOSTS statement several student positions were teased out of the data by creating categories paraphrasing common arguments. There were also "not usable" responses comprised of response sheets for which (a) no arguments were written (perhaps the student did not understand, did not have sufficient knowledge, or did not care), (b) the original statement was simply repeated, or (c) the argument had nothing to do with the statement. Finally, "unique" responses were those that pertained to the statement but offered a singular argument lying outside the form and/or content of all other arguments presented. The interjudge reliability of categorizing paragraphs into "student positions" was found to be 84%.

Because interviews require a great deal of time, 10 VOSTS statements were selected for the present study (Table I). The selection was guided by the desire to sample a wide range of STS topics, and to follow up on questions that arose in the national study (Aikenhead, 1987b; Fleming, 1987; Ryan, 1987). Each student responded to four of the 10 VOSTS statements. Various combinations of statements were employed, ensuring that each VOSTS statement had at least 10 student responses.

After writing a paragraph justifying their initial reaction to a VOSTS statement, students read the "student positions" for the same VOSTS statement that they had just reacted to; and then they chose the one that best expressed their viewpoint or, alternatively, wrote "none fit." This 30-minute writing session took place with all students at one time in each school during class hours. Within two weeks of this session, each student was interviewed for approximately 40 minutes outside of class time.

Interview Schedule

The researcher categorized students' paragraphs according to the "student positions" for each VOSTS statement. This analysis was then compared with the choice actually made by the student. Discrepancies were noted and used in the interview.

During each interview, students reread the VOSTS statement and their

TABLE I
The 10 VOSTS Statements Used in the Study

1.1	Scientists and engineers should be given the authority to decide what types of energy Canada will use in the future (e.g. nuclear, hydro, solar, coal burning, etc.) because scientists and engineers are the people who know the facts best.
2.1	Most Canadian scientists are concerned with the potential effects (both helpful and harmful) that might result from their discoveries.
4.1	Canadian scientists should be held responsible for harm that might result from their discoveries.
6.2	Science and technology offer a great deal of help in resolving such problems as poverty, crime, unemployment, overpopulation, and the threat of nuclear war.
8.2	Communities or government agencies should tell scientists what problems to investigate; otherwise scientists will investigate only what is of interest to them and not necessarily investigate the problems of interest to the country.
12.	In order to improve the quality of living in canada, it would be better to invest money in technological research rather than scientific research.
16.1	The best scientists are those who follow the steps of the scientific method.
18.1	When scientists disagree on an issue (e.g., whether or not low-level radiation is harmful), they disagree mostly because one side does not have all the facts.
20.1	Scientists are likely to be unbiased and objective, not only in their research work, but in other areas of their life as well.
21.1	There are justifiable reasons why so many canadian scientists are male, rather than there being an equal proportion of male and female scientists.

paragraph. The interviewer then probed for examples that illustrated the ideas written in the paragraph, clarified the student's interpretation of the VOSTS statement, and clarified the student's written expressions. Referring to examples and ideas initiated by a student, the interviewer asked students how they knew about those examples or ideas, or where they learned them. When a general source was mentioned (for example, TV), the student was asked to supply a specific instance (for example, a particular TV show). The interview was open ended. Students were forced to supply all the ideas and examples.

Next, students reread the "student positions" and the choice they had made. The interviewer inquired into the reasons for the choice, and the reasons behind any discrepancy between the researcher's analysis of the paragraph and the student's multiple-choice selection. Students were allowed to change their choices.

At the conclusion of the interview for each VOSTS item, students were asked, "If I read only your paragraph *or* your choice of 'student positions,' which one more clearly expresses what you really believe?"

Each of the 27 students responded to four VOSTS statements; thus there were technically 108 interviews. Four interviews were carried out consecutively with each student and were recorded on audio cassettes. There were at least 10 interviews for each of the 10 VOSTS statements.

Analysis

Detailed notes on each interview were written based on the audio tapes. An "interview summary" was composed for each of the 108 student responses. The interview summary was written in a way that complemented and explicitly expanded upon the paragraph that the student had written. Next, four pieces of information for each of the 108 student responses were juxtaposed: (a) the student's original Likert-type response to the VOSTS statement (agree, disagree, can't tell); (b) the paragraph as written by the student (with grammar corrected for ease of reading); (c) the interview summary; and (d) the "student position" chosen by the student. These data were scrutinized to discover what information seemed to be transmitted by the four types of communication: Likert-type, paragraph, semistructured interview, and empirically developed multiple choice.

Findings and Discussion

Sources of Student Beliefs

Science instruction has often been blamed for students' distorted images and misconceptions of science (Hurd, 1986). Slogans such as scientific and technological illiteracy prick the collective conscience of science educators who value relevant and authentic science instruction for their students (Roberts, 1983). VOSTS items address a number of these literacy topics. In the national IEA study, as well in other studies reported in the literature, students revealed such naive conceptions as scientific and technological experts alone are the best people to formulate science policy, scientific research is predominantly medical research, there is essentially no difference between science and technology, science and technology have little to offer in solving major social problems, and scientific models duplicate reality. (See, for example, Aikenhead, 1987b; Fleming, 1986, 1987; McInerney, 1985; Ost, 1985; Prewitt, 1983; Ryan, 1987; Schibeci, 1986).

In what way, if any, are science teachers or textbooks to be blamed for students' naive conceptions, or to be credited for students' accurate, realistic beliefs? The interview data from this study illuminate the issue considerably.

In the interview, students were asked to reflect upon the sources of their information and the experiences that had formed their beliefs. This was a difficult task for most students. They were not sure what kind of answer was expected. In order to maintain the free-response status of the interview, it was essential not to prompt them. In the interviews, students made a total of 113 references to sources that they thought were responsible for a particular idea. Some made no such references; they did not know or could not say.

Of the 10 VOSTS statements, nine addressed either the interrelationships among science, technology, and society, or the characteristics of scientists. The tenth statement addressed a traditional science classroom topic, "the scientific method" (VOSTS 16.1). For this tenth statement, there were eight references to sources of student belief, all of which mentioned science classes (and most of which were naive conceptions, as discussed below). Two other references to science classes dealt specifically with ideas of energy per se, and not with the statement's topic—democratic versus technocratic decision making on energy policy (VOSTS 1.1). In terms of the social and technological context of science, these ten references to science classes are not relevant and thus are not considered in the following analysis.

For the remaining 103 references, students cited the following sources:

TV (news and movies) & films	46%
Newspapers	16%
Magazines and books	11%
Science classes	10%
English or social studies classes	8%
Family members	8%
Personal experiences	2%

According to the students, 73% of their sources of ideas about scientists and about the social and technological context of science, came from the mass media (TV, films, newspapers, magazines, and books). Ten percent was attributed to science classes studied at some time, including elementary grades. No references were made to science textbooks, and students denied their influence when they were mentioned by the interviewer. English and social studies classes were cited almost as frequently as science classes. Some students offered the opinion that the topic under discussion was definitely not considered in any science class. Students who were taking three science classes made no more references to science classes as sources of ideas than students who were taking one or no science classes. The absence of references to science museums probably indicates a sampling bias (there are no science museums in the students' community).

These results tend to support the criticism that the social and technological context of authentic science is ignored in many science classrooms (Bybee, 1985a; Hurd, 1986; Science Council of Canada, 1984; Ziman, 1980). The results also reflect the low priority that science teachers give to STS goals, (Gabel, Samuel, Helgeson, Novak & Rutzow, 1986; Orpwood & Alam, 1984).

The Canadian students' high dependency upon the media for STS information is consistent with studies in the U.S. (Bybee & Bonnstetter, 1985) and in Australia, England, and Israel which showed that 16-year-olds acquired most of their environmental knowledge from the media. "Moreover, those who claimed they obtained their knowledge this way, rather than from school courses, were significantly more knowledgeable" (Lucas, 1983).

Science journalist Perlman (1976) expressed dismay over the poor quality of coverage offered by television, the greatest source of STS ideas for students and for the general public. After acknowledging that TV is the chief popular form of discourse in a technological society, Perlman lamented.

> But in terms of continuing discourse between scientist and citizen, American commercial television is the most bankrupt of the mass media. Except for major developments that make the front pages of virtually every newspaper, TV networks pay little attention to science news; they seem to save their talents for the spectacular. (p. 254)

Television requires strong visual images (Davies, 1979), thereby (a) eliminating many of the latest science topics in chemistry and physics, but (b) promoting health science and ecology (La Follette, 1978). This TV media phenomenon correlates with the research findings that showed that (a) grade-12 students generally believed that scientific research means medical and environmental research (Fleming, 1987; McInerney, 1985), and (b) science textbooks paint a similar misconception (Orpwood & Souque, 1984). Given these findings and this study's interview data that indicate students pay little attention to their science texts in STS matters, one can hardly avoid the speculation that students *and* textbook writers acquire their image of scientific research from the same source—television. Moreover, Bybee and Bonnstetter's (1985) survey of U.S. science teachers revealed that the teachers' main sources of information about STS topics were similar to their students—newspapers and television.

The students in the present study were no strangers to television. Some alluded to newscasts, to David Suzuki, and to daily or weekly documentaries (in Canada, W5 and The Journal), as sources of ideas that they used in discussing their responses to VOSTS. Most of the TV "addicts," as they jokingly referred to themselves, talked about the cartoons and movies in which caricatures and stereotypes played a powerfully visual role, as predicted by Davies (1979). For instance, when justifying why they felt that males are more interested in science than females (in interviews associated with VOSTS 21.1—"There are justifiable reasons why so many Canadian scientists are male, rather than there being an equal proportion of male and female scientists"), both male and female students described their image of a scientist as a diminutive, old, bald man with spectacles and a white lab coat, usually pouring chemical potions. The image does not encourage young women to enter careers in science and technology. Where does this stereotype come from? The students were almost unanimous in pointing to TV cartoons (for example, *The Flintstones, Bugs Bunny, The Muppets,* and *Sesame Street)* and movies (for example, *Red Dawn, Frankenstein,* and *Dr. Jekyll & Mr. Hyde).* According to students, the media's vivid, though mythical, portrayals of scientists adversely affect the legitimate career choices that young people make.

Some students stated that they did not really believe the media image, but they had no specific information with which to replace it, other than the vague idea that scientists must be like anyone else. Taking science courses at high school did *not* seem to have had any affect on this situation. The school curriculum provided no authentic view of a scientist. Seldom did such a view emerge from the interviews. In the absence of vivid information from science classes, students were left to learn about science from the media. As one student said:

> In school you aren't exposed to what a real scientist would do...it's all calculations, math...in biology you learn about plants.

Students felt that school never described science in terms of careers. (Those taking more science courses did not necessarily express more interest in doing science. Their inclination to take more science classes stemmed from their desire to keep their options open for postsecondary education choices.)

To conclude, who is to blame for students being uninformed about STS topics? On the one hand, the impact of popular television outweighs by far the impact of classroom instruction. Thus, one could blame, as Basalla (1976) does, the creative producers of popular TV shows and feature films, and the cartoonists of popular comic strips. On the other hand, science instruction all but ignores the social and technological context of science. Thus, the curriculum must shoulder some blame as well (Hodson, 1986: Hurd, 1986; Ziman, 1980). The challenge to teachers and curriculum developers is, therefore, to creatively use the pop science media in a way that examines the misconceptions and naive images portrayed therein, and then to help students develop various, but authentic, beliefs about STS topics (Schibeci, 1986).

The Effect of Four Modes of Communication

Likert-Type

As described above, Aikenhead, Fleming, and Ryan (1987) reported that Likert-type responses gave little guidance for understanding student viewpoints. The present study has too small a sample to warrant a comment on the students' Likert-type responses. However, it is interesting to observe how the national sample responded to the 10 VOSTS statements selected for this investigation.

Table II shows the distribution of students' Likert-type responses for each "student position" for the 10 VOSTS statements. Table II documents the number of *different* reasons ("student positions") for students picking "agree" (for example, five of them for VOSTS 1.1) or picking "disagree" (for example, seven of them for VOSTS 1.1). Students could select the same Likert-type response but for a variety of reasons, all of them masked by the Likert-type format. Also evident from Table II is the distribution of students among the categories "agree," "disagree" and "can't tell" *for each* "student position." About one-half of the "student positions" have more than 20% of the Likert-type responses lying outside one single response. As an example, of the students writing essentially the same argumentative paragraph, 70% may have agreed with a statement while 30% (more than 20%) may have either disagreed or said they couldn't tell. Although some VOSTS statements showed a fairly well-defined break between the "agree" and "disagree" responses (for example, VOSTS 1.1 and 12), others showed no clean breaks (for example, VOSTS 6.2, 18.1, and 21.1). The response "can't tell" received a significant amount of student attention for several "student positions" (4.1 C, 6.2 D, 12 E, 16.1 C and 20.1 E).

Thus, the Likert-type responses offer only a guess at student beliefs, and the chances of an evaluator guessing accurately are very remote. These results would give little credence to inferences that might have been made from the Likert-type

TABLE II
Number of Students in each Likert-Type Response for each "Student Position" of the VOSTS Statements

	STUDENT POSITIONS																										
	A			B			C			D			E			F			G			H			I		
VOSTS Statement	a	d	c*	a	d	c	a	d	c	a	d	c	a	d	c	a	d	c	a	d	c	a	d	c	a	d	c
1.1	83	1	1	15	0	0	4	2	3	0	5	1	2	9	2	0	7	2	1	25	6	0	11	2	-	-	- ^
2.1	18	1	1	5	0	1	80	1	0	3	0	1	16	0	2	2	1	3	17	0	0	3	5	1	0	4	0
4.1	45	1	2	0	70	1	2	9	11	8	0	0	0	20	4	0	7	0	2	2	4	-	-	-	-	-	-
6.2	2	17	1	10	7	3	0	8	0	14	4	18	5	3	3	63	0	0	-	-	-	-	-	-	-	-	-
8.2	2	10	3	1	37	2	5	25	5	6	7	3	7	4	4	32	2	0	8	0	1	-	-	-	-	-	-
12	33	2	1	0	1	2	0	14	5	0	6	9	1	18	17	0	24	2	0	15	0	0	2	0	0	1	1
16.1	73	0	0	2	0	1	8	17	12	1	38	2	0	8	0	0	7	3	-	-	-	-	-	-	-	-	-
18.1 +	55	6	3	6	8	2	1	24	1	3	29	6	1	12	0	2	10	2	0	2	1	-	-	-	-	-	-
20.1	2	0	0	29	0	0	2	0	0	53	3	2	2	2	13	1	15	4	0	4	3	2	12	1	1	15	2
21.1 -	6	0	0	0	12	2	8	1	2	27	4	5	5	7	1	19	8	0	12	4	4	4	4	0	1	5	0

*a, d, and c stand for "agree," "disagree," and "can't tell" responses, respectively.

^- indicates the student position did not exist for the VOSTS statement.

+The student positions for this statement are actually A, D, F, H, I, K, L, respectively.

~A tenth student position, J, shows 11, 1, and 1 for a, d, and c, respectively responses alone. (See, for example, the IEA results in Jacobson and Doran, 1986; and Tamir, 1987).

Likert scales were originally intended to be used as a comparative, quantitative measure of attitude (Likert, 1932). A Likert scale "requires a large number of monotone items, i.e., having the characteristic that the more favorable the individual's attitude toward the attitude object, the higher his expected score for the item" (Shaw & Wright, 1967, p. 24). The almost ideal, unidimensionality of Likert items lies in sharp contrast with the multidimensional aspects of authentic science with its sociotechnological context. VOSTS items stress cognition, not attitude. VOSTS items address a complex world, not a monotone attitude object. Therefore, one might have predicted the inadequacy of Likert-type scales for monitoring student beliefs about STS topics.

Paragraphs and Semistructured Interviews

The imprecision of Likert-type responses had motivated Aikenhead, Fleming, and Ryan (1987) to have students write paragraphs as part of the Canadian IEA study. The English language, however, was not perfectly precise in the hands of those students. Their paragraphs left room for interpretation. In order to assess how much interpretation—How well did grade-12 students express their views in writing?—the next logical step was to compare the content of students' written paragraphs with the content of their semistructured, open-ended interviews.

Although there is no objective scale that measures the degree of continuity between a student's paragraph and his or her interview summary, an initial, rough estimate can be made by taking advantage of the "student position" choices. One will recall from the "Research Procedures" section that students selected one "student position" after writing their paragraph, and that the researcher matched the student's paragraph with a "student position" before noting the student's choice. The degree to which the researcher and a student picked the same "student position" is an approximate indication of the continuity between the researcher's reading of the paragraph and the student's true belief that lay behind the paragraph (as evidenced by the student's interview). This continuity reflects on how well students originally expressed themselves in writing.

A stipulative definition of ambiguity is based on this procedure. An *un*ambiguous paragraph is one for which the student and the researcher independently picked the same "student position" (the student, based on his or her true belief; the researcher, based on his reading of the paragraph). An ambiguous paragraph, on the other hand, is one for which there was no such agreement. This rough estimate of ambiguity problematically assumes that the student and the researcher are both reading similar meaning into the "student positions," and that the student has written a clear and thorough account of his or her viewpoint. These assumptions are examined throughout the following discussion.

Of the 108 paragraph responses, half were found to be unambiguous. These are analyzed first.

Unambiguous Paragraph Responses. Due to space limitation, only three examples of unambiguous paragraph responses are analyzed here. (A more detailed account may be found in Aikenhead, 1987a). The three examples illustrate an unambiguous continuity among the written paragraph, the interview summary and the "student position" selected. The three students were selected for analysis on the basis of the representativeness of their responses. The grammar in student quotations has been tidied for ease of reading. The students' paragraphs, their interview summaries, and their multiple-choice selections are shown in Table III. The students had addressed the topic of technocratic versus democratic views on making a science-related social decision (VOSTS 1.1, Table I).

The data in Table III demonstrate how the interviews brought out details that went missing in the paragraphs. For example, student A spoke of radioactive spills and leaks as harmful effects, student B talked about educating the public through media commercials, and student C expressed the normative view "people should not have it forced on them." None of these ideas had appeared in the paragraphs. As well, the interviews tended to define limitations of a student's belief. For instance, student C limited his answer to socioscientific issues involving safety and cost; student B to issues involving how directly he sees the public being affected; and student A to how well scientists are informed with respect to public wishes. Although the interviews, more so than the paragraphs, focused on details and limitations to the students' beliefs, these details and limitations seemed to fall comfortably within the general expression of the "student position" chosen by each student.

In spite of the variations among the students' paragraphs, and in spite of the variations magnified by the semistructured interviews, the students basically expressed the belief captured for these students by the "student positions" they had selected. Therefore, the variations observed between paragraphs and interviews did not imply significant variations in the students' basic beliefs.

Ambiguous Paragraph Responses. The comparisons between paragraphs and interviews discussed up to this point have centered on students who were able to express their ideas quite clearly. Other results accrue from considering paragraphs which appeared to be ambiguous. Ambiguity arises for a number of reasons. Several are discussed here.

Ambiguity can occur when students are uninformed on a topic, or when they do not fully understand the statement. Their paragraphs, interviews, and "student positions" have little chance of showing continuity. A case in point is a student who forthrightly wrote that she did not know enough about scientists and engineers to offer a viewpoint on VOSTS 1.1. Her interview summary suggested a basic democratic stance on the issue at hand, but her choice of "student positions" (she picked two in spite of the directions to pick only one) incorporated both proscience and antiscience views. Moreover, she changed her choice during the interview to one that appeared to contradict her interview summary. (The researcher had categorized her paragraph as "not usable.")

Other interviews uncovered a result otherwise camouflaged by most paragraphs. Of the 12 paragraph responses to VOSTS 20.1 (concerning a scientist being unbiased and objective at work and in other areas of life), only one paragraph expressed the fact that the student did not understand the statement. However, the interviews revealed that six of the 12 students did not understand the meaning of "unbiased and objective," key words in the statement. One student thought that "unbiased and objective" meant a scientist who objected to an experiment, and he responded accordingly. Another student wrote a paragraph that seemed to be off

TABLE III

Three Students Showing Consistency Among Their Paragraph, Interview and Choice of "Student Position"

Paragraph As Written, STUDENT A

They know the facts so they can probably show what is best for Canada. Maybe one of the types listed is harmful. In some way, they should be able to find this and show better possible solutions.

Interview Summary, STUDENT A

Scientists should decide on the energy issue because, due to their knowledge, they know best how to prevent harm; e.g., radioactive spills and leaks. Similarly, scientists should decide if test tube baby programs should exist. On other issues where scientists don't know what the public wants and harm would be done (e.g., involvement in Star Wars), the public should decide.

"Student Position" Selected, STUDENT A

Scientists and engineers should decide because they have the training and facts which give them a better understanding of the issue.

....

Paragraph As Written, STUDENT B

I would agree, because the scientists etc. do know the facts, but I also think that the public should be taught, and they should be aware of what's going on, because I feel they have that right.

Interview Summary, STUDENT B

Scientists should decide because (a) the issue does not have a concrete immediate impact on the general public, and (b) scientists know the facts. But people, informed of the facts (for instance informed by media commercials), should participate in the decision (though I have no idea how). These facts are not normally discussed in biology and chemistry classes (therefore I am not informed on the energy issue). The facts let one know what's going on; e.g., what's safe, etc. When the issue is "more down to earth" (more concretely immediate) (e.g., spraying Saskatoon with pesticides) people should decide, as long as they are informed. When the issue relates to just a few people (e.g., test-tube baby research), or when the issue is further removed from the immediate concerns of the public, scientists should basically decide (e.g. energy issue and Star Wars research).

"Student Position" Selected, STUDENT B

Scientists and engineers have the training and facts which give them a better understanding of the issue, but the public should be consulted.

....

Paragraph As Written, STUDENT C

I think people should be able to chose for themselves which type of energy they want to use because one may be cheaper than another or one may be safer than another as people see it.

Interview Summary, STUDENT C

When cost or safety is an important factor (as is for future energy) in the eyes of the public (and to me), the people should decide (e.g., on nuclear power plants) because people should not have it forced on them. Scientists and engineers could give suggestions, however. When safety or cost is not a big problem (e.g., star wars systems, pesticide spraying, or fetal research) as I see it, then scientists and engineers should decide because they know what they're talking about (the public could be listened to up to a point, though only to a small extent).

"Student Position" Selected, STUDENT C

Scientists and engineers should be involved in giving advice, but the ultimate decision lies with the people.

the topic (and therefore had been categorized as "not usable") until one discovered from the interview that he thought "objective" meant "sticking to a theory until proven wrong." It would seem that some statements can unexpectedly tax the vocabulary of an average grade-12 student. Altogether, about 15% of the ambiguous paragraphs were caused by students not being informed on a topic or by students not fully understanding key terms.

While 15% of the ambiguous paragraphs are explained by a lack of student knowledge, 85% are explained by students writing incomplete paragraphs. Four categories of incompleteness were observed:

(a) A truncated paragraph (often written by students with less confidence or little concern), the meaning of which consistently surfaced in the interview and in the choice of "student position."

(b) A paragraph that happened to neglect a small but important detail (simply overlooked by the student at the time) that was consistently expressed in the interview and in the choice of "student position."

(c) A paragraph that was consistent with the interview, but both were missing an important detail mentioned in the "student position."

(d) A paragraph, interview, and "student position," all showing apparent inconsistencies for reasons undiscovered during the interview.

Categories (a) and (b) together accounted for 45% of the ambiguous paragraphs, while categories (c) and (d) each accounted for 20% of the ambiguous paragraphs. As described above, the remaining 15% was explained by students not understanding the statement or not being informed on the topic. These cases of incomplete paragraphs are discussed in detail by Aikenhead (1987a). One illustrative analysis of two students is provided below. The students had responded to VOSTS 16.1, which addresses "the scientific method."

The most typical of ambiguous cases is illustrated by student D (Table IV), whose paragraph painted a rather singular picture of what the best scientists do—"follow their own free will." The paragraph gave no clue to his belief in a stepwise scientific method. However, the interview added this second dimension to the picture—"It is possible to discover new things with the scientific method." The "student position" selected was consistent with his interview. Thus, his paragraph was incomplete with regard to a critical detail, but his interview and "student position" matched quite closely. *Forty-five* percent of the apparent ambiguities arose because students' paragraphs were too short to communicate effectively (for instance, a one-line sentence begging to be interpreted) or were missing an important bit of information that surfaced in both the "student position" and the interview.

About 20% of the ambiguous paragraphs never seemed to get resolved in the interview or in the "student position." The case of student E (Table IV) is illustrative. He *wrote* about ways of discovering things in science by "sidestepping the main idea" (the scientific method?). He *talked* about following the plan (the scientific method defined) and about deviating from it when accidental discoveries occurred or when new ideas arose. The "student position" he selected downplayed the scientific method (his plan or main idea) by emphasizing the role of accidental discoveries in science. These inconsistencies reflect the ambiguity in his paragraph. The motivation or reasons for the ambiguity were not discovered. One can only speculate that (a) the young man does not know as much as he would like

TABLE IV
Two Students Who Wrote Incomplete Paragraphs

Paragraph As Written, STUDENT D

My vision of a scientist is a person who tries to look into the new and in order to discover new ideas they must follow their own free will.

Interview Summary, STUDENT D

Scientists who follow the scientific method follow what a superior scientist had previously done; i.e., a certain method. They should go with the way they feel but this might be hard to do. It is possible to discover new things with the scientific method - they might get a better result, by accident, coincidence, or changing a procedure. On the other hand, Einstein, Galileo and the guy who discovered light were good scientists and they used their free will, not the scientific method.

"Student Position" Selected, STUDENT D

Although the scientific method is useful in many instances, it does not ensure results; thus the best scientists will also use originality and creativity.

....

Paragraph As Written, STUDENT E

There are ways of discovering things without having to plot everything a scientist does. Things can still be learned by sidestepping the main idea.

Interview Summary, STUDENT E

The scientific method is a plan, where the scientist makes up his own question, follows steps, and comes up with an answer. Along the way, the scientist may sidestep the main idea by making discoveries by accident or exploring ideas that occur to him along the way while following the plan (i.e. the scientific method). A good scientist has lots of ideas for sidestepping the plan.

"Student Position" Selected, STUDENT E

Many scientific discoveries were found by accident, not by following the scientific method.

the researcher to think he knows, or (b) the young man finds words difficult to handle in a precise way, or (c) shades of both.

Students D and E (Table IV) typify another point related to how well students appear to write paragraphs. When analyzing the national sample of paragraph responses to VOSTS 16.1, Aikenhead (1987b) discovered ambiguity due to students using different definitions of "the scientific method" without explicitly specifying a definition. The interviews in this study allowed the researcher to ask students what "the scientific method" means. The most popular definition provided was "the procedure section in a lab." Variations appear in Table IV. Thus, it made logical sense to a number of students that if you simply repeated a lab procedure, you would end up with the same results and nothing new would be discovered, and therefore the best scientists would *not* follow the scientific method. A compromise viewpoint was written *un*ambiguously by a female chemistry/physics student:

> Sometimes following the steps of scientific methods is best but in some cases it would be wise to use a little instinct and to do what you think would work better. How else are discoveries made if you follow the book and do the same thing you've done before?

In terms of the standardized science-textbook definition of "the scientific method," most students in this study's sample, and from across Canada (the national IEA sample), had acquired a misconception. Alternatively, in terms of the viewpoint that "the scientific method" is a myth to begin with (Aikenhead, 1979), many students seem ready to learn a more authentic view of scientific method and what scientists and engineers actually do (Harrison, 1985; Hodson, 1986). Of greater importance to the issue of ambiguity, students' poorly defined conceptions or their naive conceptions created ambiguous paragraphs.

Summary of Ambiguous/Unambiguous Paragraph Results. Are grade-12 students able to express in writing the beliefs they actually hold? The foregoing comparisons between written paragraphs and semistructured interviews allow several conclusions to be made. Among the cross section of grade-12 students represented by this study's sample, one-half appeared to have expressed themselves clearly in writing. When details were missing in a paragraph, these details seemed to be relatively insignificant to the general issue raised by the VOSTS statement. The other half of the sample seemed less skilled at articulating their beliefs, to varying degrees. Quite often, students wrote an incomplete paragraph; either by offering a cursory explanation or by neglecting a small but critical detail. In such cases, the interview and the choice of "student position" were consistent and they clearly compensated for an incomplete paragraph. The number of these incomplete paragraphs might have been reduced somewhat if students had been pressured into writing more thoroughly. Ambiguity in paragraphs was also accounted for by students choosing a "student position" that was seemingly inconsistent with their paragraph and interview.

The results of this study suggest that under the most favorable writing conditions, perhaps as many as two-thirds of an average grade-12 class could have conveyed unambiguously in writing a belief about a STS topic. This proportion increases dramatically when students have received instruction on the topic.

Empirically Developed Multiple Choice

The "student positions" employed in this investigation were empirically developed by analyzing a large number of paragraphs (Aikenhead, Fleming & Ryan, 1987; Ryan, 1986). These "student positions" served as a multiple-choice type of response in the present study. Thus, this response mode is labeled "empirically developed multiple choice."

In the foregoing analysis of paragraph clarity, the "student positions" were crucial points of comparison. When the researcher's categorization of a student's paragraph was the same as the student's own choice of "student position," then the paragraph was defined as unambiguous. But what would students conclude themselves if they compared the content of their own paragraph with the content of their chosen "student position"? To find out, students were asked which of the two more clearly expressed their true beliefs: their paragraph or their choice of "student position." The question was posed 108 times, once for each VOSTS response.

A large majority of respondents (73%) concluded that the "student positions" conveyed their beliefs more clearly than their paragraphs. About 4% said they were equal. The reasons for this conclusion varied. Some students mentioned their lack of ability with words. Others had found a critical idea in the "student position," an idea that they had neglected to write down or had not thought about (the incomplete paragraph subgroup). And some remarked on how clearly the "student position" was worded. In the eyes of the students, therefore, the "student position" seemed closer or equal to their true beliefs, in 77% of the cases (73% + 4%).

The remaining 23% felt that their paragraphs were more accurate. About half of these students did not have strong preferences, however. Their reasons included: "My paragraph mentions an *informed* public." "My paragraph says how *important* the decision is." "My paragraph explains a bit more—*how* scientists might use a discovery." In all of these cases, the students' paragraphs had been written clearly enough to be categorized as unambiguous; that is, the extra details found in the paragraphs turned out to be *in*significant for understanding the essential beliefs students wanted to convey. The nuances in the paragraphs were not germane to the main STS topic under consideration. About 11% of all interviews fell into this group—students having mild preferences for their paragraphs.

This left about 12% who preferred their paragraph because it contained significant information, both to them and to the researcher. Students explained: "I think my paragraph is clearer." "I put in the idea of sidestepping." "I skimmed the choices; I didn't really read them." "The statement is oversimplified."

To summarize: By interviewing students and having them compare their written paragraphs with their choices of "student positions," three groups of students were found:

(a) Those who thought their selection of a "student position" equally or more accurately reflected their true beliefs—77%.

(b) Those who thought their selection of a "student position" incompletely reflected their true beliefs, but from the researcher's perspective (having categorized the paragraph independently of the students' choice), the students' paragraphs seemed to be as clear as the "student position" they selected—11%.

(c) Those who thought their selection of a "student position" incompletely reflected their true beliefs, and from the researcher's perspective, the students had reasonable evidence for their claim—12%.

To estimate the full potential of the empirically developed multiple choices, groups (a) and (b) could be combined, thereby suggesting that as many as 88% of the students were able to convey what they essentially believed about a STS topic by responding to empirically developed multiple choices.

A fairly rough double check on this estimate is possible because during the interview students were allowed to reconsider their choice of "student position." If, as the analysis above states, 88% were able to accurately convey their beliefs via a "student position," then about 12% might be expected to change their choice as a result of reconsidering it during the interview. The interview data revealed that about 18% changed their choice during the interview. This indicates that about 82% of the students had been able to describe what they actually believed by selecting a "student position." For those students who changed their choice (18%), half switched to the "student position" which, to the researcher, had matched their paragraph. The other half, characterized by paragraphs classified as "unique" or "not usable," changed to a "student position" that appeared to differ from their paragraph. This double-check analysis supports the estimate that over 80% of the students had been able to clearly communicate their viewpoint by responding to the empirically developed multiple choices.

The results of this study support the efficacy of a multiple-choice mode for monitoring student beliefs, provided that the choices are empirically derived rather than being deduced from a philosopher's view of science. The "student positions" used in this study were written in a style that tried to capture a common argument among student responses; they were not written in a traditional multiple-choice style. Therefore, this study inadvertently served as a first field test of a roughly drafted, multiple-choice form of VOSTS. Future editions of VOSTS should (a) recast the "student positions" into a more traditional multiple-choice style, (b) modify vocabulary (for example, changing "unbiased and objective"), and (c) offer the choices, "I don't understand the topic," "I don't know enough about this subject to make a choice," and "none of these choices fit my basic viewpoint, which is...." This last choice, allowing students to write their own position, is sensitive to the more knowledgeable and articulate student who may find the choices oversimplified. As well, it allows a student to honestly say "I don't care."

Summary of Conclusions

Students growing up in a technoscientific culture develop various degrees of savvy to cope with this aspect of society. Critics of science education have pointed to the paucity of realistic beliefs and authentic knowledge offered to students by science curricula today. As new curricula are developed to meet the needs of a savvy citizen, new methods for monitoring student views on STS content must also be developed. This study investigated four different response modes for monitoring student beliefs about STS topics: Likert-type, paragraph, interview, and empirically developed multiple choice. The study also explored the sources of those beliefs.

What information was gained, and what was lost, in each of the four modes of student response? Each response mode involved trade-offs. The method that required the least amount of effort, the Likert-type response, yielded the least accurate—most ambiguous—results. Inferences based on Likert-type data will be erroneous most of the time. Science educators should rethink the way they use tests that claim to assess student views about the epistemology of science and its social and technological context.

Compared with Likert-type responses, argumentative paragraphs substantially improved the clear expression of student beliefs. Nevertheless, ambiguity lingered at approximately the 35% to 50% level because some students tended to write incomplete or inarticulate paragraphs. Yarroch (1986) also found similar results in his study of a standardized biology test. When students responded in paragraph form, they tended to understate, and sometimes not state, what they knew. In addition to the disadvantage of residual ambiguity in paragraphs, student paragraphs require a fair amount of effort to analyze and categorize on a large scale.

Compared with paragraph responses, semistructured interviews (very similar to oral tests often used by European teachers) enriched the understanding of student viewpoints by clarifying many, though not all, of the ambiguities residing in the students' written work. Of all four response modes, the interview offered the most lucid and accurate data. Its liability is the time needed to gather and analyze the data.

Finally, the "student position" choices—the empirically derived, multiple-choice response mode—reduced the ambiguity down to the 15% to 20% level. While considerable resources were needed to develop the inventory in the first place, and while the "student positions" demanded careful reading by students, its analysis was extremely straightforward. In terms of obtaining the most accurate data for the least amount of resources expended, the empirically developed, multiple-choice response mode seems to be the most efficient of all modes investigated by this study.

Although some students individually had significant problems writing ideas clearly, a large number of students collectively articulated a wide variety of ideas, as evidenced by the success of the "student positions" developed in the national study. The results of the present study suggest that students who are less adept at writing clearly are certainly capable of understanding the viewpoints expressed by their more fluent peers. This finding lends support to the development of instruments or inventories grounded in the empirical data of student viewpoints or understandings, rather than instruments structured solely by the philosophical abstractions of science educators. The literature on alternative frameworks (West & Pines, 1985) or common-sense conceptions (Mayer, 1984) is instructive here. The study also demonstrates Howe's (1985) argument that paragraph and interview data can serve to augment the validity of multiple-choice tests or inventories.

The semistructured interviews provided the opportunity to investigate the sources of student beliefs. The results of this study lend support to the critics of the mass media (Basalla, 1976; Perlman, 1976; Schibeci, 1986). Most (73%) of the interview information about STS came from the mass media. The ideas that students attributed to science classes (for example, ideas about "the scientific method") tended to be almost as inaccurate as the images conveyed by television and films. For the students participating in this study (a cross section of grade-12 students in a Canadian urban setting), the science curriculum had done little to ameliorate the media's false images and caricatures of science and scientists. These false images and caricatures were thought by many students to have a detrimental effect on young women thinking about science careers. In the absence of school instruction, students relied on the popular media's version of what science is and what scientists do. This finding answers, in large measure, Schibeci's query (1986, p. 146): "How would we establish convincingly that the poor image of scientists presented on television leads to negative attitudes among children?"

In summary, the study documented, in part, the criticism that science instruction ignores the social and technological context of authentic science, and that TV has far more influence on what students believe about science than do numerous science courses. The study also provided guidance to future efforts in monitoring student beliefs about STS topics. Likert-type methods are discouragingly inaccurate, while empirically developed multiple-choice methods—the selection of "student positions"—are most encouraging. Because the interview data were consistent with the choices of "student positions" over 80% of the time, these choices were considered to accurately represent students' beliefs about STS topics. Paragraph responses to VOSTS harbored ambiguities that were generally overcome by an interview. If time permits, classroom teachers could use paragraph responses and/or oral tests to accurately assess their students' views. These methods are seldom feasible on a large scale, however.

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