1992

Students' Preconceptions about the Epistemology of Science

ALAN G. RYAN AND GLEN S. AIKENHEAD
College of Education, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, S7N 0W0

INTRODUCTION

How do high school students view the world of the scientist? As science programs continue to emphasize an understanding of the nature of science, educators and researchers need ways of assessing students' views on a wide range of science–technology–society (STS) topics.

This article is the second of a two-part series. The first article described the development of a new type of instrument, *Views on Science–Technology–Society*, VOSTS (Aikenhead and Ryan, 1992). The instrument is an empirically derived pool of 114 multiple-choice items that assess high school students' reasoned viewpoints on a variety of issues: how science, technology, and society interact; school characterization of science; characteristics of scientists; the social construction of scientific knowledge; and the epistemology of science. A detailed list of topics is found in Table 1 of the first article.

The present article reports on the responses of grade 11 and 12 students ($N >$ 2000) to a selection of VOSTS items administered as a national survey in Canada. The selected items relate primarily to the epistemology of science and address the following issues: the meaning of science, scientific assumptions, values in science, conceptual inventions in science, scientific method, consensus making in science, and characteristics of the knowledge produced in science. These issues comprise part of the content of a number of new science curricula.

Science teachers will find these VOSTS results useful because the data reveal preconceptions harbored by typical high school students. These data can guide the design of science lessons or units. They also offer teachers a way of assessing their students' views on a wide variety of STS topics related to the nature of science.

The VOSTS results are also informative to researchers in science education. The results provide baseline data with much improved validity over instruments used in past research (Aikenhead and Ryan, 1992). Instruments with a Likert-type of response format have serious ambiguity problems (Aikenhead, 1973, 1988a). Their statements or multiple choices tend to come from philosophical positions written by science educators. VOSTS items, on the other hand, ameliorate some of these

Science Education 76(6): 559–580 (1992)
© 1992 John Wiley & Sons, Inc.
CCC 0036-8326/92/060559-22

serious limitations. VOSTS items were developed empirically by drawing heavily upon students' writing and interview responses (Aikenhead and Ryan, 1992).

The first article in this two-part series described the student-centered empirical basis to the VOSTS items and addressed the issue of the validity of such an approach. Some salient points in the first article are briefly repeated here as background information for the convenience of the reader.

BACKGROUND

Each VOSTS item was developed in a five-step process (Aikenhead and Ryan, 1992). The development of all 114 items took place over a six-year period in three distinct phases, each phase repeating the five steps in the development of different VOSTS items. The fifth step in each phase drew upon a national sample of typical grade 11 and 12 students. The sampling procedure followed the one utilized by the International Association for the Evaluation of Educational Assessment (IEA) study in Canada (Connelly et al., 1984). Schools were chosen to ensure (1) an academic cross section of grade 11 or 12 students; (2) a regional representation from across Canada; and (3) a representative proportion of urban and rural students for that region. The same school jurisdictions were used in all three phases of the study. Because each VOSTS item required a fair amount of reading, students were randomly assigned to respond to only 12–18 VOSTS items. Therefore, the sample size *per VOSTS item* was reduced from a total sample size of about 5000 to a size of 2138, 2475, and 2377 for each of the three phases, respectively. This second article of the two-part series reports on student responses related to the epistemology of science, responses obtained in step five in all three phases.

Each VOSTS item comprises a *statement* and several *student positions*. The domain of student positions for any one statement is constituted by the participation of students during the development process, not by theoretical or researcher-based perception of what the domain should be. Each item has its own code number that locates the item in a scheme of topics. In this article, however, the code is used merely for identification purposes. If the reader wishes to understand how the five digit code relates to the scheme of STS topics, the information is found in the first article (Aikenhead and Ryan, 1992).

In the presentation of the results that follows, the student positions are analyzed according to an underlying philosophical stance on the nature of scientific knowledge. That philosophical position is presented next. The student positions are not discussed in terms of earlier research findings because those findings were based on instruments whose validity has been questioned (Aikenhead, 1988a; Aikenhead et al., 1987; Aikenhead and Ryan, 1992; Lederman and O'Malley, 1990). For a review of these earlier findings, see Lederman (1992).

A PHILOSOPHICAL POSITION

The nature of scientific knowledge—its epistemological and social character—can be viewed from many perspectives. For instance, it can be conceived in terms of tacit and focal knowledge (Polanyi, 1958), or in terms of public and private science (Holton, 1978). Scientific knowledge can be viewed as being bound to a paradigm, to a research program, or to neither (Kuhn, 1970; Lakatos and Musgrave, 1970; Toulmin, 1972; respectively). And it can be appreciated as being socially constructed (Barnes and Edge, 1982; Latour and Woolgar, 1979; Longino, 1983). Because certain issues in the sociology of science, such as values and consensus making, relate directly to the epistemology of science, aspects from this sociological perspective will be used in this article to illuminate concepts in the epistemology of science.

The epistemological and associated sociological perspectives that frame this article are those explicated by Barnes (1985), Holton (1978), Kuhn (1970, 1977), Snow (1987), and Ziman (1980, 1984). These authors have explored, from a constructivist point of view, the following topics (listed in the order they appear below in the section "Results and Discussion"): the meaning of science, assumptions, values, conceptual inventions, scientific method, consensus making, and the characteristics of the knowledge produced in science. For each topic, the views of Barnes, Holton, Kuhn, Snow, or Ziman are contrasted with the views expressed by the high school students.

Student views that converge with Barnes, Holton, Kuhn, Snow, or Ziman are considered to represent a *worldly* perspective. Views that diverge from this contemporary literature are thought to be *naive.* Naive views are often identified with logical positivism:

> One vestige of logical positivism is the belief that scientific knowledge connects directly with reality, unencumbered by the vulgarity of human imagination, dogma or judgements. This ontological view is often associated with the idea that science finds absolute truth, and does so independently of the investigator's psychological and social milieu. (Aikenhead, 1987, p. 460)

Nadeau and Desautels (1984) label this epistemic view "scientism" and offer a five-category description of it.

1. *Naive realism:* Scientific knowledge is the reflection of things as they actually are.
2. *Blissful empiricism:* All scientific knowledge derives directly and exclusively from observation of phenomena.
3. *Credulous experimentalism:* Experimentation makes possible conclusive verification of hypotheses.
4. *Blind idealism:* The scientist is a completely disinterested, objective being.
5. *Excessive rationalism:* Science brings us gradually nearer the truth.

In the discussion of the study's results, naive views on the epistemology of science are often characterized by the Nadeau–Desautels descriptors of scientism, while worldly views are anchored in contemporary literature.

RESULTS AND DISCUSSION

Student responses to VOSTS items germane to the epistemology of science are reported here. This section is organized by the following topics: science, assumptions, values, conceptual inventions, scientific method, consensus making, and characteristics of the knowledge produced in science. Each topic is introduced succinctly by a perspective found in the literature on the epistemology of science. This perspective provides a conceptual framework in which the empirical results can be interpreted. The scope of this article is too narrow to present an analysis of these perspectives found in the literature.

The empirical results for each topic are interpreted in terms of (1) how students' views converge with or diverge from the perspective found in the literature; and (2) some implications for science teaching. Each section ends with a summary of the key findings for the topic.

Due to limitations of space, we only present a *selection* of tables of results. In addition, brief reference is made to some items that are not reported here in tabular form. At the end of this article, directions are provided for those wishing to obtain the student responses to the complete set of VOSTS items.

What Is Science?

Science educators often discuss science teaching in terms of science content, science process, and the social context of science. A content-oriented image of science is consistent with a logical positivist approach (Nadeau and Desautels, 1984), while a social context image is consistent with an STS approach (Bybee, 1987). Students' images of science will certainly color their views on its epistemology, and vice versa. For example, epistemology will differ greatly between students who see science as an encyclopedia of facts about the world and those who see science as a facet of Western culture. Therefore, when interpreting students' responses to questions on the epistemology of science, it will be helpful to know what students think science is.

VOSTS item 10111 addresses this topic. Generally, students were divided between the content and process perspectives; they all but ignored the social aspect of science—the STS perspective. Table 1 indicates how student responses varied. Science was seen as: a body of knowledge (28%, position B), exploring the unknown (24%, C), a social institution (2%, G), improving the world (12%, E and F), and undefinable (19%, H). Students had not acquired a uniform view of science. Their images varied in a way that reflects the debate among science educators (Bybee, 1987) and that reflects the stereotypes and caricatures of the mass media (Aikenhead, 1988a).

Related to the preconception of science as improving the world (Table 1, 12%, positions E and F), a more specific preconception was revealed when students compared the social value of scientific research with that of technological research (VOSTS item 10421; not reported here in tabular form). Thus, while students believed that science is mainly content or process, they also viewed science as an instrument of social purpose—an "instrumentalist" perspective (Barnes, 1985). This view is consistent with Fleming's (1987) work: according to a majority of students surveyed, facts and processes in science are developed in order to improve medical practice and environmental quality.

TABLE 1
Student Responses to VOSTS Item 10111

	Defining Science Is Difficult Because Science Is Complex and Does Many Things. But MAINLY Science Is:
%	Your Position, Basically:
7	A. a study of fields such as biology, chemistry, and physics.
28	B. a body of knowledge, such as principles, laws, and theories, which explain the world around us (matter, energy, and life).
24	C. exploring the unknown and discovering new things about our world and universe and how they work.
3	D. carrying out experiments to solve problems of interest about the world around us.
2	E. inventing or designing things (for example, artificial hearts, computers, space vehicles).
10	F. finding and using knowledge to make this world a better place to live in (for example, curing diseases, solving pollution, and improving agriculture).
2	G. an organization of people (called scientists) who have ideas and techniques for discovering new knowledge.
19	H. No one can define science.
1	I. I don't understand.
0	J. I don't know enough about this subject to make a choice.
4	K. None of these choices fits my basic viewpoint.

Note: The blank spaces found in most Tables (for example, between positions G and H above) are placed there on the advice and direction of the students who participated in Steps 3 and 4 of the study. Spaces and indentations make the reading easier for a majority of students. Several variations were explored.

Students' instrumentalist perspective confuses science with technology. According to Ziman (1984), the social purpose of the scientific enterprise is to generate new knowledge for its own sake (for instance, how do phages reproduce?); while the social purpose of technology is to respond to human and social needs (for instance, how to cure cancer). Thus, in terms of the literature on the epistemology and sociology of science, the Canadian students confused science with technology by thinking that medical and environmental research is science rather than being primarily technology. Such confusion is sown and nurtured by a North American myth that states: "technology is applied science" (Collingridge, 1989; Fleming, 1987, 1989; Snow, 1987), a claim explicitly prevalent in almost every science textbook today in North America. Interestingly, technology is not generally viewed that way in Europe (Fleming, 1989; Harrison, 1985). The instances of technology-driven science far exceed the instances of science-driven technology (Ziman, 1984).

About one third of the students in our sample defined technology as "the application of science" (29%, 10211 B; not reported here in tabular form), and almost three quarters oversimplified the relationship between science and technology as scientific research leading to practical applications (73%, 10411 B; not reported here in tabular form).

Summary. The North American confusion of science with technology can cloud epistemic views. This should be kept in mind as one reads the following analysis of students' views on the epistemology of science. Chances are great that when students talk about science, they are probably talking about technology, specifically medical and environmental technological investigations.

Scientific Assumptions

Since Isaac Newton (1687) wrote his "Rules" in Book III of *Mathematical Principles of Natural Philosophy*, philosophers of science have labored over the articulation of axiomatic assumptions underlying science. Margenau (1950) listed seven: logical fertility, multiple connections, permanence and stability, uniformitarianism, causality, simplicity and elegance, and empirical confirmation. These assumptions help to delineate what counts as science and what does not. For instance, the *absence* of the uniformitarianism assumption in "creation science" essentially distinguishes it from legitimate science (Anderson, 1982).

Although these fundamental assumptions are important to the epistemology of science, they were beyond the comprehension of most 11th and 12th grade students who participated in the VOSTS project. At the paragraph-writing stage in the development of the VOSTS items, students were unable to write coherently about topics such as a knowable universe, effects necessarily having causes, and the uniformity of phenomena over space and time.

Only one of the VOSTS items dealing with axiomatic assumptions survived the item development process. It was a concrete version of the uniformitarianism assumption (item 90921) dealing with the topic of science and a supernatural being or deity. The results in Table 2 provide intriguing insights into student responses. Only a minority of students (21%) sided with the scientific community by acknowledging that the uniformitarianism assumption is central to science. Of these students, 17% reasoned that science was one way of knowing about the world (position A in Table 2), and a further 4% expressed a superficial reason for their uniformitarianism view (position B). An equally small number of students (5%), on the other hand, believed that science was not limited and that scientists could investigate the supernatural (position E). By far the largest group (46%), however, subscribed to a view consistent with a creationist posture and in direct conflict with the tenets of the epistemology of science—"that a supernatural being could alter the natural world" (position D).

These results would seem to be disturbing to science educators who subscribe to a constructivist approach to teaching—getting students to construct (or reconstruct) their own meaning for phenomena (Driver, 1988; West and Pines, 1985).

TABLE 2
Student Responses to VOSTS Item 90921

%	Science Rests on the Assumption That the Natural World Can *Not* Be Altered by a Supernatural Being (for Example, a Deity). Your Position, Basically:
	Scientists assume that a supernatural being will NOT alter the natural world:
17	A. because the supernatural is beyond scientific proof. Other views, outside the realm of science, may assume that a supernatural being can alter the natural world.
4	B. because if a supernatural being did exist, scientific facts could change in the wink of an eye. BUT scientists repeatedly get consistent results.
12	C. It depends. What scientists assume about a supernatural being is up to individual scientists.
46	D. Anything is possible. Science does not know everything about nature. Therefore, science must be open-minded to the possibility that a supernatural being could alter the natural world.
5	E. Science can investigate the supernatural and can possibly explain it. Therefore, science can assume the existence of supernatural beings.
3	F. I don't understand.
8	G. I don't know enough about this subject to make a choice.
6	H. None of these choices fits my basic viewpoint.

The responses to VOSTS item 90921 (Table 2) suggest that one half of the high school students in the sample would likely be predisposed to construct personal meaning of natural phenomena in a way that entertained the possibility of an intervention by a deity and call that knowledge science. Indeed, Larochelle and Desautels (1989) hypothesize that the success of a constructivist approach to learning science may be contingent upon an adequate understanding of the epistemology of science. Accordingly, the uniformitarianism view should be made explicit during science classes so that students can learn the basis of this crucial scientific assumption.

Another assumption in the epistemology of science raises the question: Does scientific knowledge tell us what is really out there in the universe (ontology) or is scientific knowledge "mind stuff" (epistemology)? The question delineates two camps within the philosophy of science: (1) an ontological perspective consistent with logical positivism ("naive realism," Nadeau and Desautels, 1984); and (2) an epistemic perspective consistent with contemporary views (Barnes, 1985; Holton, 1978; Kuhn, 1970; Sullivan, 1933; Ziman, 1984). What do students think? Three very similar VOSTS items distinguish between (1) the act of *discovering* (for example, a miner discovers gold—a metaphor for ontology); and (2) the act of *inventing* (for example, an artist invents a sculpture—a metaphor for epistemology). VOSTS item 91013 addresses this distinction in terms of scientific theories (Table 3). A sizable minority of the students (34%) expressed a purely ontological view

TABLE 3
Student Responses to VOSTS Item 91013

For This Statement, Assume That a Gold Miner "Discovers" Gold While an Artist "Invents" a Sculpture. Some People Think That Scientists *Discover* Scientific THEORIES. Others Think That Scientists *Invent* Them. What Do You Think?

%		Your Position, Basically:
		Scientists **discover** a theory:
10	A.	because the idea was there all the time to be uncovered.
12	B.	because it is based on experimental **facts**.
12	C.	but scientists invent the **methods** to find the theories.
40	D.	Some scientists may stumble onto a theory by chance, thus discovering it. But other scientists may invent theory from facts they already know.
		Scientists **invent** a theory:
13	E.	because a theory is an interpretation of experimental **facts** which scientists have discovered.
4	F.	because inventions (theories) come from the mind—we create them.
2	G.	I don't understand.
2	H.	I don't know enough about this subject to make a choice.
4	I.	None of these choices fits my basic viewpoint.

(positions A, B, and C combined), while only 17% held to a purely epistemological view (E and F). Positioned between these two extremes was the largest group of students (40%) who viewed the emergence of theories either as scientists stumbling upon theories, or as scientists inventing them (position D). These high school students were apparently influenced by a classic but erroneous notion that many discoveries occur by accident, a notion heralded in the media and by popular writers of the history of science.

When in VOSTS item 91013 the term "theory" was replaced by the terms "hypothesis" and "law" (91012 and 91011, respectively; neither item reported here in tabular form), students expressed views very similar to their views on scientific theories. These results suggest that students were consistent in their ontological/epistemological assumptions about scientific knowledge.

Summary. In the epistemology of science certain key assumptions prevail. Two of these assumptions have been examined here: the absence of an interfering deity in natural phenomena, and the inventive character of knowledge. About one half of the students held open the possibility that *science* could rest on the assumption of an interfering deity. The inventive character of scientific knowledge, however, was embraced by about one half of the students (although only 17% were quite certain) and rejected by only one third. A belief in accidental discoveries appeared to inflate the inventive knowledge viewpoint. On the basis of these results, and the results from other items not reported here, one can say that in general the Canadian students were not well informed about assumptions in science. Their naive preconceptions (including "naive realism") could easily make them susceptible to fallacious arguments, such as those of creationists, and cause them difficulty in constructing scientific concepts. Assumptions are, by their very nature, deeply buried; the results of this study demonstrate how important it is for science teaching to make them explicit and hold them up for examination.

Values in Science

The general epistemological question: "How does a scientist know?" leads to a more specific question: "How does one decide what to believe in science?" Although scientific decisions are certainly based on empirical evidence and basic assumptions, they are also guided by values (Graham, 1981). In short, science is value-laden. In a review of the values inherent in science, Aikenhead (1985) described what "value-laden science" means. There is a cluster of values (for example, accuracy and objectivity) that guide scientists when they decide between, for instance, competing theories (Kuhn, 1970). Longino (1983) labeled this set of discipline-centered values *constitutive values*. In contrast, she identified *contextual values* as a set of ethical, ideological and cultural values external to the discipline of science. The work of Bleier (1988), Graham (1981), Longino (1983), Savon (1988), Snow (1987), and Trachtman (1981) shows how contextual values can subtly infiltrate the production of scientific knowledge. Bleier (1988) argues, for instance, that certain differences between feminine and masculine subcultures within our Western society lead to differences in the production of scientific knowledge.

Science is value-laden and encompasses two types of values—constitutive and contextual. We consider each in the following sections.

Constitutive Values. The constitutive values publicly espoused by science often contrast with the constitutive values actually practised by individual scientists (Gauld, 1982; Holton, 1978). For instance, science publicly reveres objectivity, but individual scientists often rely on their subjective hunches in the privacy of their labs. There are, therefore, two aspects to science: public and private science (Holton, 1978). Public science is reported in journals, conference proceedings and textbooks. Private science is what happens in labs and what is communicated in conversations, notebooks and personal letters. Each aspect of science (public and private) may embrace contradictory sets of values. For example, scientists may be objective or subjective, open-minded or closed-minded, and unbiased or biased, depending on whether they are engaged in public or private science (Gauld, 1982). Researchers such as Mitroff (1974) have discovered that the most credible scientists tend to be seen by their peers as operating with values associated with private science (subjective, closed-minded, and biased). Mediocre scientists, on the other hand, tend to be seen as operating solely with values associated with public science (objective, open-minded, and unbiased).

Were our students cognizant of this aspect to the epistemology of science? Only superficially. In response to Item 70811 (not reported here in tabular form) a majority of students (69%) concluded that scientists can behave differently in private science compared with public science, once the terms "private" and "public" were defined for them. However, students' views were not so worldly when asked if "the best scientists are always very open-minded, logical, unbiased, and objective in their work" (VOSTS item 60211; not reported in tabular form). In this instance, 52% of the students discounted the role played by private science values, while only 35% of the students seriously considered both sets of values as playing importing roles in science.

Contextual Values. The question, "How does a scientist decide what to believe?" lies at the confluence of epistemology and sociology. The contextually value-laden nature of science has received much attention. For instance, Trachtman (1981) concluded:

> In the presence of inconclusive scientific evidence that may be variously interpreted, the economic, political, social, and ethical dimensions of the problem are critical in deciding an individual's position. (p. 13)

In other words, the epistemology of science related to scientific opinion can be, to some extent, harnessed to a social context (Snow, 1987).

As described above, students were not well informed about the constitutive values in science. Were they any better informed about the influence of *contextual* values on science? Student views were elicited on two general issues related to value-laden science: (1) the tension between facts and values when scientists decide what to accept as legitimate knowledge; and (2) the influence of religious, ethical, and cultural contexts (including masculine and feminine subcultures) on the construction of scientific knowledge. Only the issue of masculine and feminine subcultures is addressed here.

To the extent to which contextual values of the feminine and masculine subcultures can be differentiated, these subcultures would be expected to influence scientific decisions regarding the production of scientific knowledge (Bleier, 1988; Keller, 1983; Longino, 1983). For instance, biologists tend to use the concept ("thema," Holton, 1978) of domination to explain a number of phenomena. Keller (1985) identified domination as a masculine contextual value. The high school students in the sample disagreed with Keller's view that there can be a gender influence on the production of scientific knowledge. As shown in Table 4, most students (83%, 60511 A–G) claimed that there was "no difference between female and male scientists in the discoveries they make." Two very different but popular reasons emerged:

1. "Any good scientist will eventually make the same discovery as another good scientist" (26%, 60511 A), a position associated with scientism (Nadeau and Desautels, 1984).
2. "Any differences in their discoveries are due to differences between individuals. Such differences have nothing to do with being male or female"

TABLE 4
Student Responses to VOSTS Item 60511

%	There Are Many More Women Scientists Today Than There Used to Be. This Will Make a Difference to the Scientific Discoveries Which Are Made. Scientific Discoveries Made by Women Will Tend to Be Different Than Those Made by Men.
%	Your Position, Basically:
	There is NO difference between female and male scientists in the discoveries they make:
26	A. because **any good scientist** will eventually make the **same** discovery as another good scientist.
5	B. because female and male scientists experience the **same training**.
8	C. because overall women and men are equally intelligent.
2	D. because women and men are the same in terms of what they want to discover in science.
3	E. because research goals are set by demands or desires from others besides scientists.
3	F. because everyone is equal, no matter what they do.
36	G. because any differences in their discoveries are due to differences between individuals. Such differences have nothing to do with being male or female.
11	H. Women would make **somewhat different** discoveries because, by nature or by upbringing, females have different values, viewpoints, perspectives, or characteristics (such as sensitivity toward consequences).
3	I. Men would make **somewhat different** discoveries because men are better at science than women.
1	J. Women would likely make **somewhat better** discoveries than men because women are generally better than men at some things such as instinct and memory.
0	K. I don't understand.
1	L. I don't know enough about this subject to make a choice.
2	M. None of these choices fits my basic viewpoint.

(36%, 60511 G). This is a more informed position that at least considers the human factor in the epistemology of science.

Do any students side with Bleier (1988) and Keller (1983) that gender-related contextual values can play a part in how scientists know what they know? "Yes," 11% responded (position H in Table 4), "Women would make somewhat different discoveries because, by nature or by upbringing, females have different values, viewpoints, perspectives, or characteristics such as sensitivity toward consequences."

Similar results were obtained when students reacted to the following: "Male scientists concentrate only on the facts which support an idea. Female scientists in the lab also pay attention to human values" (VOSTS item 60531; not reported here in tabular form). Gender equity was espoused by 90% of the respondents for a wide variety of reasons (for example, there is no room for values in the lab, everyone is equal no matter what the job, and individual personalities affect the attention paid to values).

Summary. The recent literature concerning the production of scientific knowledge concludes that constitutive and contextual values do have an influence on how scientists generate knowledge. Although a sizable number of students intuitively appreciated this influence, there was an equal or greater number of students who operated with a different viewpoint. Naivete abounded. While the dichotomy between public and private science made sense to most students, only one third were aware that the two aspects of science might be guided by different sets of constitutive values. Only one half of the students thought that contextual values affected scientific opinion on a science-related social issue; and this proportion dropped to one third for a purely scientific issue. Agreement on gender equity in science, however, was almost unanimously adhered to, even when contradicted by the view that gender-related values can influence the knowledge that scientists construct.

Conceptual Inventions

In the present discussion, conceptual inventions refer to models, classification schemes, hypotheses, theories, and laws. These are major commodities in the commerce of scientific epistemology.

Scientific Models. Scientific models are based on socially constructed scientific facts. Do students see models as duplicates of reality or as human inventions? As shown in Table 5, students take essentially three positions: (1) models are copies of reality (19%, 90211 A–C); (2) models come close to being copies of reality (37%, 90211 D); and (3) models are *not* copies of reality (36%, 90211 E–G). Thus, one fifth of the students (19%, 90211 A–C) held a "naive realist" view (Nadeau and Desautels, 1984) contrary to contemporary epistemology of science. The largest group of students (37%, 90211 D) do not appear to embrace a purely epistemological viewpoint. Vestiges of ontological thinking (naive realism) remain.

Classification Schemes. When students addressed the topic of classification schemes, there was a shift away from the "naive realism" viewpoint (duplication reality). In response to 90311 (not reported here in tabular form) only 9% of students believed classification schemes matched the way nature really is, whereas fully 81% recognized the human inventive character of scientific classification schemes. Apparently, students were more familiar with the epistemology of classification schemes than they were with models. Unfortunately, more science-related public debates (such as the greenhouse effect) center on models than on classification schemes.

TABLE 5
Student Responses to VOSTS Item 90211

Many Scientific Models Used in Research Laboratories (Such as the Model of Heat, the Neuron, DNA, or the Atom) Are Copies of Reality.

%	Your Position, Basically:
	Scientific models ARE copies of reality:
0	A. because scientists say they are true, so they must be true.
11	B. because much scientific evidence has proven them true.
8	C. because they are true to life. Their purpose is to show us reality or teach us something about it.
37	D. Scientific models come close to being copies of reality, because they are based on scientific observations and research.
	Scientific models are NOT copies of reality:
15	E. because they are simply helpful for learning and explaining, within their limitations.
13	F. because they change with time and with the state of our knowledge, like theories do.
8	G. because these models must be ideas or educated guesses, since you can't actually see the real thing.
2	H. I don't understand.
4	I. I don't know enough about this subject to make a choice.
2	J. None of these choices fits my basic viewpoint.

Hypotheses, Theories, Laws. Although the terms hypothesis, theory and law have been variously defined, the following definitions tend to be widely accepted (Klopfer, 1966). Theories are *explanations* (often mechanistic and associated with visual representations called models) in which scientists place a high degree of confidence. Laws are general *descriptions* that enjoy a high degree of scientific confidence (often associated with classification schemes). Hypotheses are very tentative explanations or descriptions that guide investigations. In other words, theories and laws are different types of statements, and both are distinguished from hypotheses by virtue of the degree to which they have been accepted by the scientific community.

Do high school students view hypotheses, theories, and laws as different types of statements? Only 9% of the students held such a view (90511; not reported here in tabular form). The majority (64%) expressed a simplistic hierarchical relationship in which hypotheses become theories and theories become laws, depending on the amount of "proof behind the idea." Students appear to be ignorant of the fact that many laws in science were known before any theories were developed to explain them. Boyle's Law is a case in point.

Summary. Students' preconceptions revealed a considerable misunderstanding of hypotheses, theories, and laws. "Naive realism" (Nadeau and Desautels, 1984) characterized students' views on the nature of scientific models; only classification schemes were correctly understood to be epistemic rather than ontological in nature. The challenge to science educators is almost overwhelming. Student naivete concerning the epistemology of scientific knowledge could seriously undermine current attempts to increase scientific literacy.

Scientific Method

Over the years epistemologists have generally agreed that there is no such thing as "the scientific method"—that five-step or seven-step description of how to do science, included in Chapter One of most science textbooks (Beveridge, 1950; National Academy of Science, 1989). Perhaps the originators of *the* scientific method were attempting to rewrite the history of science as a "logical reconstruction" (Holton, 1978) or perhaps they mistook the writing style of scientific articles for an accurate description of how the scientific work was actually done. What are students' views on "the scientific method"?

Students apparently ignore the traditional textbook formulations of the scientific method. In an investigation that served as a precursor to the present study (an investigation employing open-ended, written responses to VOSTS statements), Aikenhead (1987) concluded, "No student explicitly mentioned the textbook classic five-step or seven-step procedure" (p. 470) when students argued whether or not the best scientists "follow the steps of the scientific method." Therefore, the multiple-choice version of the same VOSTS item (item 90611; not reported here in tabular form) does not contain the classic textbook view as one of its positions.

But what *do* students think? When they were asked to choose a description (90611; not reported here in tabular form), the largest group (40%) selected the position that read: "questioning, hypothesizing, collecting data, and concluding." This student position developed in steps 2, 3, and 4 in the development of item 90611 (Aikenhead and Ryan, 1992). The position represents a composite of several closely overlapping viewpoints. According to the student interview data obtained in steps 3 and 4, students interpret this position as a composite, and *not* as an approximation of "the scientific method" described in science textbooks.

The next largest group (13%) chose the position that described the scientific method as: "testing and retesting—proving something true or false in a valid way." The remaining students spread their choices over the other eight positions. Only 2% chose the option which stated that "there really is no such thing as the scientific method" even though this position represents the most contemporary view.

When students were asked whether the best scientists "follow the steps of the scientific method" (Table 6; VOSTS Item 90621), they tended to favor those positions which suggest that there is, to a greater (Position A, the "credulous experimentalism" view; Nadeau and Desautels, 1984) or lesser extent, a definite pattern to doing science (64%, A–C). A substantial number of students (E; 17%) were drawn to the notion of serendipitous discoveries, a view harbored by media writers. Few students (9%) chose D, the contemporary view of most epistemol-

TABLE 6
Student Responses to VOSTS Item 90621

%	The Best Scientists Are Those Who Follow the Steps of the Scientific Method. Your Position, Basically:
18	A. The scientific method ensures valid, clear, logical, and accurate results. Thus, most scientists will follow the steps of the scientific method.
4	B. The scientific method should work well for most scientists; based on what we learned in school.
42	C. The scientific method is useful in many instances, but it does not ensure results. Thus, the best scientists will *also use* originality and creativity.
9	D. The best scientists are those who use any method that might get favorable results (including the method of imagination and creativity).
17	E. Many scientific discoveries were made by accident, and not by sticking to the scientific method.
0	F. I don't understand.
6	G. I don't know enough about this subject to make a choice.
4	H. None of these choices fits my basic viewpoint.

ogists—that scientists "use any method that might get favorable results." The idea of using *any* method corresponds in most students' minds to the idea that there is no such thing as *the* scientific method.

Summary. Students tended to hold a vague preconception that the scientific method was "questioning, hypothesizing, collecting data, and concluding." A negligibly small proportion of students embraced the pragmatic view that scientists use any method that might get results (Beveridge, 1950). Students' naive views regarding scientific method amplify the problems that science educators have identified concerning how laboratories are run in science classes (Hodson, 1988).

Consensus Making in Science

How do scientists know what to believe? How do they decide? Peer review is the usual formal process (Ziman, 1984). Kuhn (1970) emphasized the importance of an informal group commitment to establishing a disciplinary matrix (paradigm) within which verification and scientific communication occurs. Formally or informally, scientific knowledge is ultimately established by a consensus among self-appointed experts (Barnes, 1985; Kuhn, 1970). The issues related to consensus making interpenetrate the domains of epistemology and sociology of science, as do contextual values (discussed above). Emphasis here is again placed on the relationship with the epistemology of science.

Students were evenly divided over the role of consensus making in science. The results are shown in Table 7. While 45% appreciated the role of consensus making in science (70231 B, C), 47% did not (70231 A, D, E, F). Of this 47%, most did not understand consensus making. They naively thought that a consensus was

TABLE 7
Student Responses to VOSTS Item 70231

When a New Scientific Theory Is Proposed, Scientists Must Decide Whether to Accept It or Not. Scientists Make This Decision by Consensus; That Is, Proposers of the Theory Must Convince a Large Majority of Fellow Scientists to Believe the New Theory.

%	Your Position, Basically:
	Scientists who propose a theory must convince other scientists:
31	A. by showing them conclusive evidence that proves the theory true.
5	B. because a theory is useful to science only when most scientists believe the theory.
40	C. because when a number of scientists discuss a theory and its new ideas, scientists will likely revise or update the theory. In short, by reaching a consensus, scientists make the theory more accurate.
	Scientists who propose a theory do NOT have to convince other scientists:
6	D. because the supporting evidence speaks for itself.
4	E. because individual scientists will decide for themselves whether to use a theory or not.
6	F. because an individual scientist can apply a theory as long as the theory explains results and is useful, no matter what other scientists believe.
1	G. I don't understand.
3	H. I don't know enough about this subject to make a choice.
3	I. None of these choices fits my basic viewpoint.

achieved in science by showing conclusive evidence that proved a theory true (31%, 70231 A)—"credulous experimentalism" (Nadeau and Desautels, 1984). The remainder of the 47% simply rejected consensus making as a way of deciding whether to accept a new theory (16%, 70231 D–F).

What scientists take as scientific truth may be affected by more than a brilliant scientist. Scientific truth can be affected by the people with whom the scientists work (Ziman, 1984). The collectivization and socialization of science in the 20th century has led scientists to work in research teams or for industrial companies. As a consequence, loyalty to the team or company can affect what scientists accept as scientific knowledge (Ziman, 1984; Jacobson, 1983). VOSTS item 70121, not reported here in tabular form, addressed the notion of a scientist's loyalty to the ideals of science being replaced by a loyalty to his or her employer. Many students (48%) tended to view this issue predominantly from the perspective of individuality—some scientists follow the ideals of science while others put the interests of the company first. Only a minority of students (24%) appreciated the influence that loyalties to an employer could have, while others (14%) outright rejected the idea.

Summary. Less than half of the students in the sample were aware that consensus is the basis of scientific knowledge. "Blind idealism" conditioned the epistemic preconceptions of the majority of students, causing them to disregard the role of personal and subjective influences on the production of scientific knowledge.

Characteristics of the Knowledge Produced in Science

Scientists engaged in consensus making draw upon empirical evidence, assumptions, and their values to reach a conclusion on the "truth" of a conceptual invention (or on the adequacy of an experimental procedure). Their conclusions constitute scientific knowledge. This knowledge is probabilistic, tentative, and paradigm bound (Kuhn, 1970; Ziman, 1984). VOSTS items addressed all three characteristics but only the tentative nature of knowledge is discussed here.

Tentative Knowledge. Although VOSTS item 90411 addresses the tentativeness of scientific knowledge, it does so without mentioning the term "tentative." As evidenced by Table 8, virtually all the students in the sample agreed that scientific knowledge changes. But their reasons revealed four very different and somewhat conflicting views:

1. Old facts change and become different facts.
2. Old facts become wrong facts.

TABLE 8
Student Responses to VOSTS Item 90411

	Even When Scientific Investigations Are Done Correctly, the Knowledge That Scientists Discover from Those Investigations May Change in the Future.
%	Your Position, Basically:
	Scientific knowledge changes:
36	A. because new scientists **disprove** the theories or discoveries of old scientists. Scientists do this by using new techniques or improved instruments, by finding new factors overlooked before, or by detecting errors in the original "correct" investigation.
31	B. because the old knowledge is **reinterpreted** in light of new discoveries. Scientific facts can change.
9	C. Scientific knowledge APPEARS to change because the **interpretation** or the application of the old facts can change. Correctly done experiments yield unchangeable facts.
15	D. Scientific knowledge APPEARS to change because new knowledge is **added on** to old knowledge; the old knowledge doesn't change.
1	E. I don't understand.
2	F. I don't know enough about this subject to make a choice.
3	G. None of these choices fits my basic viewpoint.

3. Old facts do not change; only their interpretation and application changes.
4. Old facts do not change; new facts are simply added to old facts.

Each viewpoint is discussed here, in conjunction with the student responses shown in Table 8.

A contemporary "constructivist" view in the epistemology of science acknowledges that scientific facts themselves can change with time, in light of new conceptual schemes that may reinterpret those facts differently (Kuhn, 1970). The continual reconstruction of scientific knowledge was cited as the explanation for its tentativeness by 31% of the students (position B in Table 8). (This result should not be misconstrued as suggesting that these students necessarily held a Kuhnian view. More in-depth research would be required to support such a claim.)

A falsificationist position (Popper, 1963) was embraced by 36% of the students (position A in Table 8) in which science was seen to progress by disproving the scientific knowledge of the past.

Yet a different viewpoint is revealed by position C (held by only 9%), a position which discounts theory-laden facts.

An out-dated epistemic perspective describes the progress of science as simply an accumulation of knowledge (15%, Table 8, position D).

Therefore, to say that students believed that scientific knowledge is tentative says very little indeed (a conclusion supported by the work of Lederman and O'Malley, 1990). It is more meaningful to point out that two thirds of the high school students were about equally divided between a constructionist and a falsificationist view on the epistemology of science, and that the other students believed facts were unchangeably true, a view identified as "excessive rationalism" by Nadeau and Desautels (1984).

Summary. Students' views on the tentativeness of scientific knowledge were equally divided among three different perspectives: constructivists, falsificationists, and "excessive rationalists." All in all, however, a majority of students held worldly preconceptions about scientific knowledge being tentative.

CONCLUSION

This article shows how VOSTS, a new research tool, documents students' reasoned beliefs about the following topics in the epistemology of science: scientific assumptions, values in science, conceptual inventions, scientific method, consensus making in science, and characteristics of the knowledge produced in science. Because the choices for each VOSTS item were derived empirically from students' views (rather than from science educators' philosophical positions), a researcher can feel secure in the validity of student responses; that is, the meaning that students read into the VOSTS choices tends to be the same meaning that students would express if they were interviewed.

The purpose of our study was to acquire baseline data on students' preconceptions on the epistemology of science. Our results are not encouraging. But nor are they surprising. The Science Council of Canada (1984) reported that no consistent instruction took place across Canada to provide students with an authentic view of the nature of science. Since preliminary studies using VOSTS in the United States indicate that American and Canadian students respond similarly to the items (Brunkhorst, 1987), one might expect a comparable degree of "scientism" among American high school graduates.

When Gallagher (1991) examined the viewpoints about the nature of science portrayed to students in American secondary schools, he examined two data sources: textbooks and teachers' classroom practice. Our study adds to this line of research by looking at *students'* views on the epistemology of science. Gallagher (1991, p. 132) concluded that the image of science portrayed to students is "both inaccurate and inappropriate." Our results support this conclusion.

Many science educators believe that science teaching needs to move away from the impersonal, scientistic, and socially sterile depiction of science that is the current norm of North American high schools, toward an STS or a history/philosophy approach in harmony with contemporary epistemology (Aikenhead, 1985; Bybee, 1987; Duschl, 1988; Gruender and Tobin, 1991; Hodson, 1988; Hurd, 1987). They have warranted their beliefs in several ways, including (1) the need for school science to be presented in an everyday context relevant to students; (2) the desire to see science represented in an intellectually honest way; and (3) the disturbing evidence that traditional school science is actually discouraging bright students—especially bright young women—from choosing science- and technology-based careers (Bondi, 1985; Entwistle and Duckworth, 1977; Oxford University, 1989). The results of the present study support the claim that if science instruction is going to convey accurate and appropriate images of science, it must be brought into line with contemporary epistemology.

Gruender and Tobin (1991) have outlined the institutional and intellectual constraints that stand in the way of reconceptualizing science teaching. The naive views on the epistemology of science documented by this study underscore the necessity of overcoming those constraints. Although it is easy to suggest that science teachers should make realistic views of science more explicit to their students, specific instructional methods are needed for teachers to do a better job. Ryan (1992) outlines how VOSTS items themselves can be used in science classrooms for diagnostic, assessment, and evaluation purposes. Aikenhead (1988b) offers an instruction guide for teaching science through an STS approach. Central to such an approach are instructional strategies (such as small group work, student-centered discussions, simulations, and decision making) that provide concrete opportunities for teachers to make realistic views of science more explicit to students.

Copies of the complete VOSTS inventory of 114 items are available on a cost-recovery basis by writing to: VOSTS, Department of Curriculum Studies, College of Education, University of Saskatchewan, Saskatoon, SK, S7N 0W0, Canada.

The research was funded by Grant Number 410-87-1051 from the Social Science and Humanities Research Council of Canada. The work and advice of Pat Thomas, research assistant, is greatly appreciated.

REFERENCES

Aikenhead, G. S. (1973). The measurement of high school students' knowledge about science and scientists. *Science Education, 57*(4), 539–549.

Aikenhead, G. S. (1985). Collective decision making in the social context of science. *Science Education, 69*(4), 453–475.

Aikenhead, G. S. (1987). High school graduates' beliefs about science-technology-society. III. Characteristics and limitations of scientific knowledge. *Science Education, 71*(4), 459–487.

Aikenhead, G. S. (1988a). An analysis of four ways of assessing student beliefs about STS topics. *Journal of Research in Science Teaching, 25*(8), 607–627.

Aikenhead, G. S. (1988b). *Teaching science through a science-technology-society-environment approach: An instruction guide*. Regina, Canada: SIDRU, Faculty of Education, University of Regina.

Aikenhead, G. S., and Ryan, A. G. (1992). The development of a new instrument: "Views on Science-Technology-Society" (VOSTS). *Science Education, 76*(5), 477–491.

Aikenhead, G. S., Fleming, R. W., & Ryan, A. G. (1987). High school graduates' beliefs about science-technology-society. I. methods and issues in monitoring student views. *Science Education, 71*(2), 145–161.

Anderson, E. C. (1982). *Creation, evolution, and science teaching in the secondary school*. Unpublished doctoral dissertation, University of Toronto.

Barnes, B. (1985). *About science*. Oxford: Basil Blackwell.

Barnes, B., & Edge, D. (1982). *Science in context*. Cambridge, MA: MIT Press.

Beveridge, W. (1950). *The art of scientific investigation*. New York: Norton.

Bleier, R. (1988). *Feminist approaches to science*. New York: Pergamon Press.

Bondi, H. (1985). Society's view of science. In G. B. Harrison (Ed.) *World trends in science and technology education*. Nottingham, UK: Trent Polytechnic.

Brunkhorst, H. K. (1987). A comparison of student/teacher positions on selected STS topics: A preliminary study. In K. Riquarts (Ed.) *Science & technology education and the quality of life*. Vol. II. Kiel, Germany: Institute for Science Education.

Bybee, R. W. (1987). Science education and the science-technology-society (STS) theme. *Science Education, 71*(5), 667–683.

Collingridge, D. (1989). Incremental decision making in technological innovations: What role for science? *Science, Technology, & Human Values, 14*(2), 141–162.

Connelly, F. M., Crocker, R., & Kass, H. (1984). *A case study of science curriculum in Canada*. Vol. VII. Toronto: Ontario Institute for Studies in Education.

Driver, R. (1988). Theory into practice II: A constructivist approach to curriculum development. In P. Fensham (Ed.) *Development and dilemmas in science education*. New York: Falmer.

Duschl, R. (1983). Comments on "An analysis of prospective science teachers' understanding the nature of science." *Journal of Research in Science Teacing, 20*(4), 373–376.

Duschl, R. (1988). Abandoning the scientistic legacy of science education. *Science Education, 72*(1), 51–62.

Entwistle, N. J., & Duckworth, D. (1977). Choice of science courses in secondary school: Trends and explanations. *Studies in Science Education, 4*, 63–82.

Fleming, R. W. (1987). High school graduates' beliefs about science-technology-society. II. The interaction among science, technology, and society. *Science Education, 71*(2), 163–186.

Fleming, R. W. (1989). Literacy for a technological age. *Science Education, 73*(4), 391–404.

Gallagher, J. J. (1991). Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. *Science Education, 75*(1), 121–133.

Gauld, C. (1982). The scientific attitude and science education: A critical reappraisal. *Science Education, 66*(1), 109–121.

Graham, L. R. (1981). *Between science and values.* New York: Columbia University Press.

Gruender, C. D., & Tobin, K. (1991). Promise and prospect. *Science Education, 75*(1), 1–8.

Harrison, G. B. (Ed.) (1985). *World trends in science and technology education.* Nottingham, UK: Trent Polytechnic.

Hodson, D. (1988). Toward a philosophically more valid science curriculum. *Science Education, 72*(1), 19–40.

Holton, G. (1978). *The scientific imagination: Case studies.* Cambridge: Cambridge University Press.

Hurd, P. (1987). A nation reflects: The modernization of science education. *Bulletin of Science Technology Society, 7*(1), 9–13.

Jacobson, M. F. (1983). When scientists testify for hire. *Science 83, 4*(6), 18.

Keller, E. F. (1983). *A feeling for the organism: The life and work of Barbara McClintock.* San Francisco: W. H. Freeman.

Keller, E. F. (1985). *Reflections on science and gender.* New Haven, CT: Yale University Press.

Klopfer, L. E. (1966). *History of science cases.* Chicago: Science Research Associates.

Kuhn, T. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago: University of Chicago Press.

Kuhn, T. (1977). *The essential tension.* Chicago: University of Chicago Press.

Lakatos, I., & Musgrave, A. (Eds.) (1970). *Criticism and the growth of knowledge.* Cambridge: Cambridge University Press.

Larochelle, M., & Desautels, J. (1989). "Of course, it's just obvious": Adolescents' ideas of scientific knowledge. A paper presented at the First International Conference of the History and Philosophy of Science in Science Teaching, Florida State University, Tallahassee, November.

Latour, B., & Woolgar, S. (1979). *Laboratory life: The social construction of scientific facts.* London: Sage.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29*(4), 331–359.

Lederman, N. G., & O'Malley, M. (1990). Students' perceptions of tentativeness in science: Development, use, and sources of change. *Science Education, 74*(2), 225–239.

Longino, H. (1983). Beyond "bad science": Skeptical reflections on the value-freedom of scientific inquiry. *Science, Technology, and Human Values, 8*(1), 7–17.

Margenau, H. (1950). *The nature of physical reality: A philosophy of modern physics.* New York:McGraw-Hill.

Mitroff, I. (1974). Norms and counter-norms in a selected group of the Apollo moon scientists: A case study of the ambivalence of scientists. *American Sociological Review, 39,* 579–595.

Nadeau, R., & Desautels, J. (1984). *Epistemology and the teaching of science.* Ottawa: Science Council of Canada.

National Academy of Science. (1989). *On being a scientist.* Washington, DC: National Academy Press.

Newton, I. (1687). *Philosophiae naturalis principia mathematica.* In F. Cajori (translator, 1962), *Sir Isaac Newton's mathematical principles of natural philosophy and his system of the world.* Berkeley: University of California Press.

Oxford University Department of Educational Studies. (1989). *Enquiry into the attitudes of sixth-formers towards choice of science and technology courses in higher education.* Oxford, UK: Department of Educational Studies.

Polanyi, M. (1958). *Personal Knowledge*. Chicago, IL: University of Chicago Press.
Popper, K. R. (1963). *Conjectures and refutations*. New York: Harper Torchbooks.
Ryan, A. G. (1992). A way of expanding classroom assessment to meet the STS agenda in secondary school science. In R. Yager (Ed.), *The status of science-technology-society reform efforts around the world*. ICASE 1992 Yearbook. Knapp Hill, South Harting, Petersfield, UK GU31 5LR: International Council of Associations for Science Education.
Savon, B. (1988). *Science under siege: The myth of objectivity in scientific research*. Toronto: CBC Enterprises.
Science Council of Canada. (1984). *Science for every student: Educating Canadians for tomorrow's world*. Ottawa: Science Council of Canada.
Snow, R. E. (1987). Core concepts for science and technology literacy. *Bulletin of Science Technology Society, 7*(5/6), 720–729.
Sullivan, J. W. N. (1933). *The limitations of science*. New York: Mentor Books.
Toulmin, S. (1972). *Human understanding*. Princeton, NJ: Princeton University Press.
Trachtman, L. E. (1981). The public understanding of science effort: A critique. *Science, Technology, and Human Values, 6*(3), 10–15.
West, L. H., & Pines, A. L. (Eds.) (1985). *Cognitive structure and conceptual change*. New York: Academic Press.
Ziman J. (1980). *Teaching and learning about science and society*. Cambridge: Cambridge University Press.
Ziman, J. (1984). *An introduction to science studies: The philosophical and social aspects of science and technology*. Cambridge: Cambridge University Press.

Accepted for publication 19 June 1992