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Whose Nature of Science?

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Abstract: Science education literature explicitly and implicitly advocates basic tenets (criteria) for "the nature of science." The purpose of this study was to investigate whether the science education tenets are also held by philosophers of science (those who study purported tenets of science), and furthermore, to reveal possible related philosophical positions underpinning differences in responses among the philosophers. The philosophers of science expressed significant disagreements with the tenets, and different philosophers of science varied on their views about the tenets. In addition, relationships were found among the philosophers' views of the nature of science, their views of philosophy of space, and with their philosophy of science in general. Therefore, the tenets that are advocated as basic criteria for science education's "the nature of science" must be reconsidered so that more accurate criteria may be developed for future nature of science research. J Res Sci Teach **34:** 39–55, 1997.

Much has been written about accuracy portraying "the" nature of science (NOS) to teachers and students. For more then half a century there has been an overwhelming consensus of science education literature and science organizations as to the necessity of instructing science teachers and/or their students in the NOS (American Association for the Advancement of Science [AAAS], 1989; Carey & Stauss, 1970; Gruender & Tobin, 1991; Hurd, 1960; National Society for the Study of Education, 1960; National Science Teachers Association [NSTA], 1982; Lederman, 1992; Saunders, 1955). Today it is a major goal, if not *the* major goal, of science education (Matthews, 1994). However, even given this objective's long history, the vast majority of studies concluded that it has not been, nor is it being, achieved by the students (Lederman & O'Malley, 1990; Mackay, 1971; Miller, 1963; National Assessment for Educational Progress, 1988; Rubba, Horner, & Smith, 1981; Ryan & Aikenhead, 1992) or the teachers (Anderson, 1950; Eve & Dunn, 1990; Johnson & Peeples, 1987; King, 1991; Klopfer & Cooley, 1961; Zimmermann, 1991).

The studies using more quantitative methodologies were usually conducted with NOS instruments (e.g., FAS, TOUS, NOSS, NSKS, SPI, TSAS, WISP).[1] Inherent in these instruments is the assumption that they are based on valid philosophical models. However, "their statements or multiple choices tend to come from philosophical positions written by science educators," not philosophers of science (Ryan & Aikenhead, 1992, p. 559). Two decades ago Lucas (1975) pointed out that the developers of current instruments of the time, NOSS, SPI, TSAS, and in

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particular TOUS, needed to "recognize that conflicting models of science exist" and recommended that they "explicitly specify the philosophic assumption(s) of the instruments " (p. 484).

More recently, qualitative methodologies have had greater use with regard to NOS research. These studies usually examined how closely students' and/or teachers' views resembled those views of the major national organizations (i.e., AAAS, NSTA). More often, however, these studies never explicitly present criteria or the philosophic assumptions underpinning the criteria but simply report the results of the study, such as: "these . . . teachers were unable to articulate a deep, coherent understanding of the nature of science" (Gallagher, 1991, p. 127).

The bases for arrival at the tenets, whether in quantitative or qualitative instrumentation and related reporting, is almost universally absent from the literature. Following are 39 popular tenets explicitly and implicitly stated in the science education literature from the past 15 years on which the subsequent study was initially based. The basic tenets of the NOS scale are, according to Lederman (1983, pp. 47–48):

- The fundamental driving force in science is curiosity concerning the physical universe.
- Science is a dynamic, on-going activity, rather than a static accumulation of information.
- Science aims at ever-increasing comprehensiveness and simplifications using mathematics as a simple, precise method of stating relationships.
- There is no 'one' scientific method, but as many methods as there are practitioners.
- The methods of science are better characterized by some value-type attributes than by techniques.
- A basic characteristic of science is faith in the susceptibility of the physical universe to human ordering and understanding.
- Science has a unique attribute of openness, both of mind and openness of the realm of investigation.
- Tentativeness and uncertainty are characteristic of all science.

Giddings (1982, pp. 21–24) recorded that "certain characteristics of science seemed to have attained some degree of consensus within the profession:

- There exists an objective, external world, independent of the existence of an observer.
- There is belief in the uniformity of nature, hence a belief in the reproducibility of phenomena.
- The fundamental diving force in science is curiosity concerning the physical universe. It has no connection with outcomes, applications, or uses, aside from the generation of new knowledge . . .
- The conceptual schemes elaborated by scientists are fundamental to further discoveries and to the formulation of hypotheses that will lead to further discoveries . . .
- Science begins inductively by noting facts: it then places these facts in a context of theory. Then proceeding from theoretical premises, it makes predictions with respect to the facts in a deductive way. Every completed piece of scientific reasoning has an inductive and a deductive branch.
- The methods of science are characterized by attributes which are more of the nature of values then techniques. Among these traits of science are, dependence upon sense experience, insistence on operational definitions, recognition of the arbitrariness of definitions and schemes of classification or organization, and the evaluation of scientific work in terms of reproducibility, and of usefulness in furthering scientific inquiry.
- Science possesses the attribute of openness, an openness of mind, allowing for willingness to change opinion in the face of evidence, and an openness with respect to the investigation, unlimited by such factors as religion, politics, or geography.

- Tentativeness and uncertainty mark all of science. Nothing is ever completely proven in science, and recognition of this fact is a guiding consideration of the discipline."

Some in the past have challenged the philosophical underpinnings of science education's NOS (Stenhouse, 1985; Duschl, 1985, 1988; Hodson, 1986), and to add to the previous list of tenets, Cleminson (1990, pp. 437–438) and others have advanced "new" basic tenets claiming that "the following assumptions could be used as a foundation.

- Scientific knowledge is tentative and should never be equated with truth. It has only temporary status.
- Observation alone cannot give rise to scientific knowledge in a simple inductivist manner.
- We view the world through theoretical lenses built up from prior knowledge.
- There can be no sharp definition between observation and inference.
- New knowledge in science is produced by creative acts of the imagination allied with the methods of scientific inquiry. As such science is a personal and immensely human activity.
- Acquisition of new scientific knowledge is problematic and never easy.
- Abandoning cherished knowledge that has been falsified usually occurs with reluctance.
- Scientists study a world of which they are a part, not a world from which they are apart."

In 1989, Aikenhead, Ryan, and Fleming developed a new type of instrument purportedly not in the quantitative paradigm but in the interpretative paradigm, *Views on Science–Technology–Society* (VOSTS). In Ryan and Aikenhead's (1992) study reporting students' preconceptions about the epistemology of science based on VOSTS, "student views that converge with Barnes (1985), Holton (1978), Kuhn (1970, 1977), Snow (1987), or Ziman (1980, 1984) are considered to represent a *worldly* perspective. Views that diverge from this contemporary literature are thought to be *naive*" (Ryan and Aikenhead, 1992, p. 561). Furthermore, they stated that "The naive views on the epistemology of science documented by this study [their study based on VOSTS] underscore the necessity of overcoming those [institutional and intellectual] constraints" (p. 577). These classifications and subsequent call for action clearly represent a normative use of VOSTS by its creators. Some of the basic NOS tenets implicit in the VOSTS study are (Ryan & Aikenhead, 1992):

- The social purpose of the scientific enterprise is to generate new knowledge for its own sake.
- Technology is not applied science.
- Uniformitarianism is an axiomatic assumption which helps delineate what counts as science and what does not.
- An ontologic perspective consistent with logical positivism is naive.
- Science rests on the assumption that the natural world cannot be altered by a supernatural being.
- Consensus among self-appointed experts is the basis of scientific knowledge.

In 1993, the AAAS' Project 2061 Benchmarks' authors clearly stated some NOS tenets: Students should know that

- Scientists assume that the universe is a vast single system in which the basic rules are the same everywhere. The rules may range from very simple to extremely complex, but scientists operate on the belief that the rules can be discovered by careful, systematic study.

- This [science's] ongoing process leads to an increasingly better understanding of how things work in the world but not to absolute truth. Evidence for the value of this approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions.
- There are different traditions in science about what is investigation and how, but they all have in common certain basic beliefs about the value of evidence, logic, and good arguments. And there is agreement that progress in all fields of science depends on intelligence, hard work, imagination, and even chance.
- Scientists in any one research group tend to see things alike, so even groups of scientists may have trouble being entirely objective about their methods and findings. For that reason, scientific teams are expected to seek out the possible source of bias in the design of their investigation and in their data analysis. Checking each other's results and explanations helps, but that is no guarantee against bias.
- In the short run, new ideas that do not mesh well with mainstream ideas in science often encounter vigorous criticism. In the long run, theories are judged by how they fit with other theories, the range of observations they explain, how well they explain observations, and how effective they are in predicting new findings.
- Modern science is based on traditions of thought that came together in Europe about 500 years ago. People from all cultures now contribute to that tradition.
- Science disciplines differ from one another in what is studied, techniques used, and outcomes sought, but they share a common purpose and philosophy, and all are part of the same scientific enterprise.
- When it comes to participation in research that could pose risks to society, most scientists believe that a decision to participate or not is a matter of personal ethics rather than professional ethics.
- Deliberate deceit is rare and likely to be exposed sooner or later by the scientific enterprise itself. When violations of these scientific ethical traditions are discovered, they are strongly condemned by the scientific community, and the violators than have difficulty regaining the respect of other scientists (AAAS, 1993, pp. 8, 13, 19–20).

More recently, the National Association of Biology Teachers published a position statement contending that natural processes can be "explained by valid scientific principles, and clearly differentiate and separate science from various kinds of nonscientific ways of knowing . . ." (Alters et al., 1995, p. 4).

With myriad tenets in circulation, the question arises: Who decides for science education organizations and researchers the primarily philosophically based question of what are the tenets of the NOS? Intuitively, many may contend that because scientists do science, they are the most appropriate ones to make the decision. However, Pomeroy (1993) stated that "the literature contains conflicting opinions and data as to the current philosophical status of scientists" (p. 262). In addition, Shapiro (1994) held that "most working scientists are not philosophically sophisticated" (p. 34). Moreover, Pitt (1990) was critical of today's scientists, contending that they are not knowledgeable in the NOS. He stated that "we really can't blame the scientists since they generally don't even know the history of their own discipline" (p. 16).

Clearly we must call to authority, to those who study purported tenets of the natural sciences—the philosophers of science—not only to examine the various basic tenets of the NOS held by science education organizations and researchers, but to provide some insight into establishing more accurate criteria for the NOS. This is not to suggest that a consensus of philosophers of science be used to construct *one* set of basic tenets, but that some scheme might be developed wherein multiple sets of views from the philosophers could be organized into useful accurate criteria. Given this philosophically pluralistic approach, a more appropriate measuring of students' and teachers' views might be accomplished.

Purpose of the Study

The purpose of this study was to obtain views of philosophers of science concerning science education organizations' and researchers' commonly held NOS tenets. In addition, the philosophers' of science criticisms and recommendations of these existing tenets and the various related philosophical underpinnings of their views were elicited. This was done in the hope of portraying a more accurate view on which to base criteria to conduct future NOS research.

Sample

The sample was drawn from members of the Philosophy of Science Association (PSA) holding a Ph.D. or D.Sci. and the rank of assistant professor (or equivalent or higher rank) in philosophy at a U.S. institution of higher learning. This defined population numbered 418. The PSA was chosen because it is the largest organization of philosophers of science. A sample size of 210 was chosen using Krejcie and Morgan's (1970) table for determining sample size such that a 5% margin of error and a 95% confidence level could be established.

Research Design and Procedures

The design was based on the premise that the community of philosophers of science is a population with variation among individuals, and therefore, may be investigated as such.

A pilot study was conducted in which the 39 NOS tenets, verbatim from the literature, as preceding, were numbered and sent to 20 PSA members possessing the sample criteria mentioned previously. The sample of philosophers was randomly selected from the population of 418 using a random number table. A letter explaining the rationale of the study with subsequent solicitation of recommendations and criticisms was included. The participants were asked to select those tenets on which they believed philosophers of science would not agree. All 20 surveys were returned; however, 2 were not completed owing to participant time constraints. The tenets, in which 50% or more of the pilot study participants selected (15), were placed verbatim from the literature, on the final survey (Appendix A). This cutoff was selected for survey brevity (two pages) to engender a high response rate.

Two major recommendations resulted from the pilot study. First, the addition of questions regarding respondents underlying philosophy of science, via the evidential basis of theories in general, would shed additional light on the views concerning the NOS. In addition, the literature states: "for several reasons, the question of the evidential basis for belief in a geometric hypothesis provides rather remarkable illumination of the question of the evidential basis of theories in general" (Sklar, 1974, p. 9). Therefore, it was decided to include instrument items concerning four historically basic philosophies about the epistemology of theories of the structure of space (geometry) which might correlate with the data concerning the NOS and other aspects of the study. Second, including working definitions of some of the four basic philosophical terms would help avoid confusion. In addition, the literature showed that many terms are used in differing capacities (Matthews, 1994, p. 164). Therefore, the working definitions were included with the final survey (Appendix B). These working definitions include three basic aspects: (a) a concise definition of the major point(s), (b) a brief historical context, and (c) some rationale as to why advocates hold the view. These working definitions were synthesized from the consensus of writings listed in the bibliography and are not considered to be universal definitions.

The 20 pilot study participants were excluded from participating in the final survey study. The following were the hypotheses central to the study:

- There are major criticisms of the basic tenets of the NOS.
- Different philosophers of science vary in their views about the basic tenets of the NOS.
- There is a correlation between philosophy of space and views on the NOS.
- The views of philosophers of science on space correlate with their views on philosophy of science in general.
- There are multiple fundamental positions of philosophy of space and philosophy of science in general that serve as philosophical underpinnings for current philosophers' of science views of the NOS.

Instrumentation

The survey consisted of 20 items. Items 1–15 were a list of 15 tenets of the NOS, verbatim from the literature, with a Likert-type four-point scale designed to measure the extent to which participants agree with each tenet. Item 16 was an open-ended question giving participants an opportunity to add to or delete any of the previous 1–15 tenets. Items 17 and 18 solicited participants to indicate their strength of belief in philosophies, via percentages, as they relate to the epistemology of theories of the structure of space (geometry) and the epistemology of scientific theories in general, respectively. Item 19 inquired about supernatural causes and empiricism. Item 20 asked if (a) universal criteria(on) for demarcating science from nonscience has been found.

Test–retest reliability of responses was based on the same version of the instrument having been given (approximately 10-day separations) to 15 philosophers randomly selected in a method identical to that of those selected in the pilot study. Item-by-item estimates of reliabilities ranged from .84 to .97. The survey guaranteed confidentiality and included a self-addressed, stamped return envelope. (For the complete survey, see Appendix A.)

Results and Discussion

A total of 187 surveys were returned, constituting an 89% return rate. Seven partially completed surveys and 4 that did not fall within the studies' inductively generated categories, as subsequently discussed, were discarded, which resulted in 176 usable surveys. Any participant changes made to correct an item's tenet were counted as "disagree." Item 19 was criticized by many participants as being internally self-contradictory; therefore, it was eliminated.

With regard to possible related philosophical positions underpinning any differences in tenet responses among the philosophers, 11 philosophical positions became evident based on the frequency of percentages reported in Items 17 and 18. (Items 17 and 18 solicited respondents' strength of belief in four basic philosophies.) The positions are listed in Table 1, with blanks representing 0% representation. Four surveys were discarded whose strengths of beliefs in the four given philosophies did not fall into one of the 11 positions. Those participants who did not

Table 1
Percentages and frequencies of philosophical positions via Items 17 and 18

		Strength of Belief, by Percentage			Item 17		Item 18	
Position	A Priorism	Conventionalism	Positivism	Realism	%	*f*	%	*f*
1				↑	13.1	23	12.5	22
2			X	X	5.7	10	7.4	13
3		↓		↑	9.1	16	8.0	14
4		X	X	↑	9.7	17	10.2	18
5		↑		↑	9.1	16	8.0	14
6		↑	X	X	5.1	9	6.8	12
7		↑			9.7	17	8.0	14
8	X	X	X	↑	10.2	18	15.9	28
9	X	X	X	X	15.3	27	10.2	18
10	X	↑	X	X	6.3	11	4.0	7
11	Other philosophy				6.8	12	9.1	16

Note. ↑ = 50–100%, X = 24–50%, ↓ = 5–23% when three or less philosophies are indicated. When four philosophies are indicated, ↑ = 51–100%, X = 5–25%.

hold any strength of belief in the given four philosophies, yet offered another philosophy in the open-ended portion of Items 17 and 18, were recorded as Position 11.

Table 2 indicates the results of the multivariate analysis of variance (MANOVA) for strength of belief in philosophies as they relate to the epistemology of theories of the structure of space (geometry), on agreement with NOS tenets. Philosophical position did have a significant effect on agreement with NOS tenets, $F(14, 150) = 2.02$, $p < .001$.

Table 3 presents the results of univariate analysis on each of the 15 NOS tenets among the 11 structure of space philosophical positions. A philosophy of space position effect was found for 9 of the 15 NOS tenets: Tenet 3 ($F = 2.64$), Tenet 4 ($F = 2.26$), Tenet 7 ($F = 2.20$), Tenet 10 ($F = 2.72$), Tenet 11 ($F = 3.94$), Tenet 12 ($F = 4.50$), Tenet 13 ($F = 3.20$), Tenet 14 ($F = 2.41$), and Tenet 15 ($F = 3.05$) with degrees of freedom (10, 165) and level of significance at .05. No philosophy of space position effect was found on the other 6 NOS tenets.

Table 4 indicates the results of MANOVA for strength of belief in philosophies as they apply to the epistemology of scientific theories in general, on agreement with NOS tenets. Philosophical position did have a significant effect on agreement with NOS tenets, F (135, 1284) = 2.00, $p < .001$.

Table 2
Multivariate analysis of variance for structure of space philosophical position on Nature of Science tenets

Test Name	Value	*F*	*df*	*p*
Pillais	1.54	1.94	14, 150	.00*
Hotellings	2.08	2.07	14, 150	.00*
Wilks	.17	2.02	14, 150	.00*

*$p < .001$.

Table 3
Univariate analysis of each of the 15 Nature of Science (NOS) tenets for structure of space philosophical position

NOS Tenets	Hypothetical *MS*	Error *MS*	*F*	*p*
1	0.17	0.17	1.00	.44
2	0.11	0.44	0.78	.65
3	0.60	0.23	2.64	.00*
4	0.29	0.13	2.26	.02*
5	0.40	0.24	1.70	.08
6	0.17	0.88	1.88	.05
7	0.49	0.22	2.20	.02*
8	0.20	0.25	0.81	.62
9	0.34	0.23	1.46	.16
10	0.60	0.22	2.72	.00*
11	0.58	0.15	3.94	.00*
12	0.89	0.20	4.51	.00*
13	0.24	0.74	3.20	.00*
14	0.34	0.14	2.41	.01*
15	0.68	0.22	3.04	.00*

Note. Univariate F tests with (10, 165) *df*. *MS* = mean squares.
*$p < .05$.

Table 5 presents the results of univariate analysis on each of the 15 NOS tenets among the 11 general philosophical positions. A general philosophical position effect was found for 6 of the 15 NOS tenets: Tenet 2 ($F = 1.90$), Tenet 3 ($F = 4.02$), Tenet 5 ($F = 1.92$), Tenet 11 ($F = 6.39$), Tenet 14 ($F = 2.26$), and Tenet 15 ($F = 2.37$) with degrees of freedom (10, 165) and level of significance at .05. No general philosophical position effect was found on the other 9 NOS tenets.

The difference between the philosophical positions of Item 17 on the agreement with NOS tenets as a composite score was tested using a one-way ANOVA (Table 6). Positive responses to Items 1–15 were coded “0” and negative responses were coded “1.” The sum of these codings represented a composite agreement score. A significant difference was indicated for Item 17, $F(10, 165) = 3.40$, $p < .05$, and consequently, the one-way ANOVA, was followed by a Scheffé procedure. These tests indicated the following order of increasing tenet agreement with regard to the structure of space philosophical position: Positions 9, 11, 8, 2, 7, 5, 4, 3, 1, 6, and 10. Positions 9 and 10 were significantly different at the .05 level. No significant difference was indicated for the philosophical positions of Item 18 with NOS tenets.

Table 4
Multivariate analysis of variance for general scientific philosophical position on agreement with Nature of Science tenets

Test Name	Value	*F*	*df*	*p*
Pillais	1.51	1.90	14, 150	.00*
Hotellings	2.07	2.07	14, 150	.00*
Wilks	.17	2.00	14, 150	.00*

*$p < .001$.

Table 5
Univariate analysis of each of the 15 Nature of Science (NOS) tenets for general scientific philosophical position

NOS Tenets	Hypothetical *MS*	Error *MS*	*F*	*p*
1	0.13	0.18	0.76	.66
2	0.26	0.14	1.90	.04*
3	0.85	0.21	4.02	.00*
4	0.18	0.14	1.34	.21
5	0.45	0.24	1.92	.04*
6	0.14	0.09	1.53	.13
7	0.19	0.24	0.80	.63
8	0.21	0.25	0.85	.58
9	0.31	0.24	1.32	.23
10	0.41	0.23	1.77	.07
11	0.85	0.13	6.39	.00*
12	0.39	0.23	1.70	.09
13	0.12	0.08	1.51	.14
14	0.32	0.14	2.26	.02*
15	0.55	0.23	2.37	.01*

Note. Univariate *F* tests with (10, 165) *df, MS* = mean squares.
*$p < .05$.

Frequencies and percentages of responses to items 1–15 and 20, and correlations coefficients of the philosophical positions of Items 17 and 18 with NOS tenets are reported in Table 7. For correlation purposes the philosophical Positions 1–10 (Table 1) were considered continuous (Position 11 was considered categorical, and therefore excluded). Items 17 and 18 had 8 and 6 significant correlations, respectively. Disagreement with Tenets 1–15 and 20 ranged from 9.1% (Item 13) to 80.1% (Item 20), suggesting that there is no unanimity of agreement among participants with regard to any of the NOS tenets.

The philosophies of space belief (Item 17) was significantly correlated with general scientific philosophies (Item 18) ($r = .79$, $p < .001$), indicating that for philosophers of science, strength of belief in philosophies as they relate to the epistemology of theories of the structure of space were associated with their strength of belief in philosophies as they apply to the epistemology of scientific theories in general. The responses to Item 16, which solicited participants to indicate what they would like to see added or deleted to Tenets 1–15, were disparate. No emergent categories were apparent, suggesting that there was a lack of consensus concerning what should be included in NOS tenets. Many took the opportunity to express their concern that

Table 6
Analysis of variance summary table of structure of space philosophical positions

Source	*SS*	*df*	*MS*	*F*	Probability
Between groups	571.5	10	57.15	3.405	0.001*
Within groups	2769.2	165	16.78		

Note. Total sum of squares = 3340.7.
*Significant at the .001 level.

Table 7
Frequencies and percentages of Items 1–15 and 20, and correlations with Items 17 and 18

	Agree		Disagree		Correlation (r)	
Item	f	%	f	%	Item 17	Item 18
1	137	77.8	39	22.2	.02	.01
2	146	83.0	30	17.0	−.06	−.07
3	78	44.3	98	55.7	−.16*	−.09
4	147	83.5	29	16.5	−.03	−.07
5	98	55.7	78	44.3	.21*	.23*
6	158	89.8	18	10.2	.21*	.16*
7	109	61.9	67	38.1	.00	.01
8	81	46.0	95	54.0	.00	−.08
9	106	60.2	70	39.8	−.17*	−.20*
10	74	42.0	102	58.0	.09	−.01
11	39	22.2	137	77.8	−.32*	−.34*
12	109	61.9	67	38.1	−.21*	−.17*
13	160	90.9	16	9.1	−.07	.03
14	143	81.3	33	18.8	.22*	.17*
15	83	47.2	93	52.8	.15*	.10
20	19	10.8	141	80.1	Uncertain: $f = 16$, % = 9.1	

Note. Items 1–15 are coded so that high numbers indicate disagreement.
*$p < .05$.

most of the listed NOS tenets were being disseminated as tenets of the NOS within the science education community; one participant summed up the feelings of many by stating: “I hope you are wrong about beliefs of science educators.”

Conclusions

Science education literature and organizations clearly present that the NOS is a major, if not *the* major, goal in science education. Even though this goal has been espoused for many decades, it has reportedly not been achieved. The criteria for proclaiming that this goal has not been achieved are found primarily in the form of science education instruments, studies, and formal organizations’ statements and standards.

This study revealed that those who examine a primarily philosophical matter such as the criteria for the NOS—the philosophers of science—express major criticisms of some of the criteria’s basic tenets and that different philosophers of science vary on their views about the tenets of the NOS. Therefore, many of the existing NOS tenets, which are commonly taken as factual, must be reconsidered in light of this study so that new criteria may be developed for future research.

This study also addressed the philosophical underpinnings of philosophers with regard to their views on science education’s NOS tenets. There is a relationship between philosophy of space and views on the NOS; philosophers’ of science major philosophies of space correlate with their philosophy of science in general; and a minimum of 11 fundamental philosophy of space positions are held by philosophers of science today. Therefore, there is no one agreed-on philosophical position underpinning the existing NOS in science education.

The implication for the science education research community and its formal organizations is that we should acknowledge that no one agreed-on NOS exists. Given this philosophically pluralistic approach, a more appropriate measure of students' and teachers' views may be accomplished. The author, along with others, is currently studying the feasibility of developing an instrument that will address these matters. While it may be some time before such an instrument is available, the developers are hopeful that one can be constructed.

The author thanks Frank Arntzenius, Associate Professor of Philosophy at the University of Southern California, for generously contributing his time and expertise to the study.

Appendix A: Survey[2]

To what extent do you agree with the following:

	Strongly Agree	Agree	Disagree	Strongly Disagree
1. The fundamental driving force in science is curiosity concerning the physical universe.	❑	❑	❑	❑
2. Science aims at ever-increasing comprehensiveness and simplifications using mathematics as a simple, precise method of stating relationships.	❑	❑	❑	❑
3. The methods of science are better characterized by some value-type attributes than by techniques.	❑	❑	❑	❑
4. A basic characteristic of science is faith in the susceptibility of the physical universe to human ordering and understanding.	❑	❑	❑	❑
5. Science has a unique attribute of openness, both of mind and openness of the realm of investigation.	❑	❑	❑	❑
6. There exists an objective, external world, independent of the existence of an observer.	❑	❑	❑	❑
7. An ontological perspective consistent with logical positivism is naive.	❑	❑	❑	❑
8. Uniformitarianism (the assumption that phenomena are the product of natural forces operating over long periods of time with considerable, though not necessarily total, uniformity) is an axiomatic assumption that helps delineate what counts as science and what does not.	❑	❑	❑	❑
9. Scientific knowledge is tentative and should never be equated with truth. It has only temporary status.	❑	❑	❑	❑
10. Science rests on an assumption that the natural world cannot be altered by a supernatural being.	❑	❑	❑	❑
11. Consensus among self-appointed experts is the basis of scientific knowledge.	❑	❑	❑	❑
12. There can be no sharp definition between observation and inference.	❑	❑	❑	❑
13. Scientists operate on the belief that the basic rules of the universe can be discovered by careful, systematic study.	❑	❑	❑	❑
14. There are different traditions in science about what is investigated and how, but they all have in common certain basic beliefs about the value of evidence, logic, and good arguments.	❑	❑	❑	❑
15. Science disciplines differ from one another in what is studied, techniques used, and outcomes sought, but they share a common purpose and philosophy.	❑	❑	❑	❑

(continues on next page)

16. The above statements (nos. 1–15) are basic tenets of the nature of science held by science educators. What, if anything, would you add or delete from the list?
____
____
____
____
____

17. Indicate your strength of belief in each of the following four basic philosophies as they relate to the epistemology of theories of the struct ore of space (geometry). For example, a priorism: 20%; conventionalism: 35%; positivism: 35%; realism: 10% (to total 100%). For interphilosopher consistency, please use the enclosed working definitions.
A priorism ______ Conventionalism ______ Positivism ______ Realism _______
Other(s) (Please explain) _______________
____
____
____
____

18. Indicate your strength of belief in these philosophies as they apply to the epistemology of scientirfic theories in general.
A priorism ______ Conventionalism ______ Positivism ______ Realism _______
Other(s) (Please explain) _______________
____
____
____

19. Should supernatural causes be considered in science if empirical evidence points to such causes? ❑ Yes ❑ No
20. Has (a) universal criteria(on) for demarcating science from nonscience been found? ❑ Yes ❑ Uncertain ❑ No

Appendix B: Four Working Definitions Describing Different Views on the Epistemology of Theories of the Structure of Space (Geometry)

A priorism

A priorists hold that one can know which scientific theory is true by pure reason, independent of any sense experience. Traditionally, it is a view that is specifically tied to the structure of space. According to this view, one can know the structure of space by pure reason alone, completely independent of observation or experience of what the structure of space is.

Basically this is the view most Greeks had about all of science. Prior to the Greeks, almost nothing is known about epistemologic views about geometry. Why would the Greeks have had this view? Euclid derived, in a logical way, virtually all interesting aspects about geometry from five postulates. These postulates seemed to him and most Greek philosophers of science to be obviously true statements. They believe that one did not have to go out in the world and check whether they were true via sensory experience. Therefore, by pure reason one can figure out all the truths of geometry (i.e., all the correct things there are to say about the structure of space). Geometry for the Greeks was a model for how all science should operate.

This view was dominant until British empiricism in the 18th century. The empiricists contended, in general, that this is not the way you do science; you conduct experiments and make observations. To test and arrive at, say, Newtonian mechanics, one must do experiments. However, even when it appeared that the empiricists seemed to get the upper hand and most everyone agreed that to do science one needs to do experiments, with respect to geometry the a priorists still had a strong case, because here it still did not appear that one needed to perform experiments. Experiments, it seemed, could not make any difference regarding our beliefs (e.g., that the shortest distance between two points is a straight line). It seemed obviously true, and it seemed that one can derive all the interesting statements of geometry from those kinds of simple statements. Even though empiricists might be right about other parts of science, clearly the structure of space is something that one can figure out by good reasoning, by deriving nonobvious things from obvious things.

Kant maintained that one can know a priori what the structure of space is, because it is a concept that the mind supplies; or more generally, that any way we have of conceptualization of reality involves space with a particular structure. The concept of space is a precondition to the possibility of sense experience. In particular, he contended to know a priori that space had to be Euclidean. In addition to Kant, Descartes and Leibniz were major proponents of a priorism.

Conventionalism

According to conventionalism there is no such thing as the unique, correct geometry of the world; one has to decide by convention which structure space possesses (i.e., whether it is curved or not, etc.). It is by convention that one decides which scientific theories are true—or at least, this is true of some parts of scientific theories. Some or perhaps all features of geometry or space are not fixed by nature but can be fixed by minds in the sense that they can be fixed by convention. One convention may be easier and simpler to work with than another, but the question as to which one is true or correct does not have an answer, because there simply is not a unique, true, or correct convention.

Poincaré, one of history's greatest mathematicians, argued that we cannot somehow know whether space is Euclidean or non-Euclidean (curved or not). One cannot do experiments to figure out whether space is curved or not; one cannot reason a priori whether space is curved or not; you just have to make a conventional decision (e.g., I am just going to treat as if it is Euclidean). Poincaré contended that laws sometimes appear a priori true; however, this is only because the laws are worded in a manner such that there can be no discrepant empirical evidence.

Why did Poincaré advocate conventionalism with respect to the structure of space? He did so for four reasons: First, there exist consistent non-Euclidean axioms that describe curved space, a space in which the angles of a triangle do not add to 180°. Second, our current sensory experience is compatible with Euclidean and non-Euclidean space; in fact, our current sensory experiences are compatible with any number of claims about the geometry of space. Third (actually a generalization of the second point), experiences are always compatible with many different geometries, not just the experiences one has had, but any experiences one could have. Fourth, simplicity is not a guide to truth.

There is a sense in which a priorism plays a role in conventionalism, in that the decision-making process of conventionalism can be completely independent of any sense experience. The structure of space is not part of nature; there is not a unique space and structure out there; it is part of our theorizing about space. And there is no uniquely correct way to theorize about space. Kant, however, held that there is only one way we can theorize about it. That space is part of our concept, and our mind is so constrained as to allow only one way of conceptualizing space. Poincaré agreed with Kant that the structure of space is not part of the world; it is not out there, but it is part of our theorizing about worlds. However, Poincaré disagreed with Kant that there is only one way of doing it. He thought there are many different ways, some of which might be pragmatically more acceptable, but none of which are truer than the others.

Positivism (Also Called Reductionism, Empiricism, or Instrumentalism)

Positivism contends that once one defines one's concepts in any part of science completely (e.g., operationally), then experiment and observation will uniquely determine which is the correct theory. There are many different ways in which one could define one's terms, and those correspond to the differently formulated theories that could be true of the same world. Conventionalism holds that one must decide between Theory *Y* and Theory *Z* by convention; positivists would respond by stating if one defines things one way, then Theory *Y* will be true, and if one defines things another way, then Theory *Z* will be true.

If one cannot decide what structure space has on the basis of experiments, it is because one has not defined the concepts properly. As long as one has defined the concepts clearly enough (e.g., connected to a particular experimental procedure for measuring them), then the experiment will decide the structure of space. The basic point of positivism, then, is that empirically equivalent theories mean the same (two theories mean the same if they have exactly the same empirical consequences). Unlike conventionalism, no choice must be made between two empirically equivalent theories; both are true or both are false. For instance, a non-Euclidean theory without universal forces is an identical theory to a Euclidean geometry joined with a physics that postulates certain universal forces. In addition to Mach and Berkeley, Bridgeman clearly fell under the above description of positivism, while Reichenbach and Carnap were, roughly speaking, positivists with some realist tendencies.

Realism

In general, if one is a realist about science, then one believes that some theories are true and some are false, and in some cases, experiments and/or reason can tell you whether they are true or false. The basic characterization of the realist position is that there is an objective truth that is independent of what one is thinking. This objective truth has nothing to do with convention, definitions, or reason (good thinking). For example, space has a particular structure, but neither reason nor experiment might determine what it is (one might not be able to know what in fact the structure is). The basic feature of realism is that empirically equivalent theories do not always mean the same thing; at most, one of them is true.

There are basically two classes of realists: optimist-realists and pessimist-realists. The optimist-realists claim that although we can never be certain that we have the true theory, we nevertheless can have reasons to differentiate between empirically equivalent theories. The pessimist-realists contend that no experiment or any bit of reason could tell which of a set of empirically equivalent theories is the correct theory. The truth, in some cases, may never be known. Some pessimist-realists think science should be done not because one wants to know the truth about what happens in areas one cannot observe directly; rather that science concerns itself with the observable consequences of theory, and that is why one ought to do science. Pessimist-realists are also known as skeptical-realists or constructive-empiricists and could also be characterized as pragmatic-realists.

Advocates of realism included Planck, Newton, and Einstein. Bohr, who had positivist inclinations with respect to quantum mechanics, and Einstein, who had realist inclinations with respect to quantum mechanics, were involved in one of the most popularized debates in science concerning the Copenhagen interpretation of quantum mechanics, in which their philosophical differences played a major role.

Notes

[1] FAS, Facts About Science Test, see Wilson (1954); TOUS, Test on Understanding Science, see Klopfer and Cooley (1961); NOSS, Nature of Science Scale, see Kimball (1968); NSKS, Nature of Scientific Knowledge Scale, see Rubba and Anderson (1978); SPI, Science Process Inventory, see Welch (1966); TSAS, Test on the Social Aspects of Science, see Korth (1969); WISP, Wisconsin Inventory of Science Processes, see Scientific Literacy Center (1970).

[2] Because of APA style requirements, the formatting of this survey differs from that of the survey sent to participants. Furthermore, the introductory explanatory text that accompanied the survey has been excluded for publication brevity.

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