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ABSTRACT

This study investigated which classroom variables are related to changes in students' (N=409) conceptions of the nature of scientific knowledge. Eighteen high school biology teachers/classrooms were compared with respect to students' conceptual changes on six aspects of the nature of science (amoral, creative, tentative, testable, parsimonious, unified) as measured by the Nature of Scientific Knowledge Scale (NSKS). In addition, comparisons of overall student changes were performed. Thirty classroom variables significantly differentiated between the "high" (exhibiting the largest student change) and "low" (exhibiting minimal student change) of teachers/classrooms on at least five aspects of the nature of science. In general, teachers/classrooms in the "high" group were typified by frequent, inquiry-oriented questioning, little emphasis on rote memory, decreased seat work, and increased emphasis on depth, breadth, and accuracy of subject matter. In addition, teachers in these classrooms were more pleasant, supportive, and had established better rapport than those of the "low" group. Finally, implicit references to the nature of science were more commonly found in the "high" group. Eleven additional variables were also found to differentiate between the "high" and "low" teacher/classrooms on less than three subscales of the NSKS. Implications of these and other results are noted. (Author/JN)

Relating Teaching Behavior and Classrom Climate To Changes in Students' Conceptions of The Nature of Science

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The Nature of Science

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Introduction

Improving the scientific literacy of the public is the most compelling challenge facing science educators (National Science Teachers Association, 1982). Furthermore, an adequate conception of the nature of science is considered to be a distinguishing attribute of the scientifically literate individual (Collette & Chiappetta, 1984; Klopfer & Cooley, 1963; NSTA, 1982; Showalter, 1974). The "nature of science" has been defined in numerous ways, but it most commonly refers to the values and assumptions inherent to scientific knowledge (e.g., tentativeness, parsimony, empirically based, amoral, etc.).

Researchers have long been dismayed by the apparent misconceptions held by secondary school science students (Bady, 1979; Cooley & Klopfer, 1963; MacKay, 1971; Mead & Metraux, 1957; Rubba, Horner, & Smith, 1981) as well as those misconceptions possessed by science teachers (Carey & Stauss, 1968, 1970; Miller, 1963; Schmidt, 1967). Consequently, much time and effort have been invested in programs specifically designed to improve science teachers' conceptions of science with the anticipation that improved student conceptions would necessarily follow. Such programs (Billeh & Hassan, 1975; Carey & Stauss, 1968, 1970; Welch & Walberg, 1968; among others) clearly assumed that a teacher's classroom behavior is influenced by his/her conceptions of the nature of science and that a significant positive relationship, therefore, exists between teachers' conceptions and changes in the conceptions of their students. However, recent research (Lederman, 1983) has failed to support this rather intuitive notion. In addition, curricula specifically designed to promote improved conceptions of the nature of science have provided only limited success. Thus, after three decades of research concerned with the "nature of science" we know little more than that we are unhappy with the conceptions currently held by our secondary school students.

Research on teaching has provided strong empirical support for the relationship of teacher behavior and classroom climate to a wide variety of student outcomes (Medley, 1979). Indeed, Herron (1977) has described a student's conceptions of the nature of science as a values system which is taught implicitly via the teacher's classroom behavior. Interestingly, research focusing on "conceptions of the nature of science" as a student outcome has virtually ignored the influence of teacher behavior and classroom climate.

The purpose of this research was to identify those classroom variables (i.e., teacher behaviors and classroom climate) which are related to changes in high school students' conceptions of the nature of science. The findings reported here represent the culmination of over two years of research. Preliminary descriptive data have been reported elsewhere (Lederman, in press). Prior to this investigation little was known about how teachers may influence students' conceptions. However, this research provides the knowledge that will help promote more adequate conceptions of the nature of science and improved scientific literacy.

Subjects

The subjects consisted of 18 senior high school biology teachers and the students from one randomly selected tenth grade biology class of each teacher. A total of 409 students (22.72 per classroom) constituted the student sample. Each classroom was heterogenous with respect to sex, race, and socioeconomic status.

The teacher sample only included individuals with a minimum of five years of teaching experience. Consequently, a mean of 15.83 years of experience characterized the teacher sample. Seven of the teachers were female and 11 were male.

The 18 classes included in this investigation represented urban (six classes), rural (one class), and suburban (eleven classes) populations. A maximum of three classes were studied in any one particular school. All instruction followed the New York State Regents Syllabus (State Education Department, 1982), which specifies an "understanding of the nature of science" as an objective.

Method

A blend of quantitative and qualitative techniques best served the purpose of this study. In general, the design was largely derived from the approach developed for the beginning teacher evaluation study (Tikunoff, Berliner, & Rist, 1975).

During the first week of the fall semester, the "Nature of Scientific Knowledge Scale" (NSKS; Rubba, 1976) was administered to each teacher as well as to the students in his/her class. At the end of the fall semester, both groups were administered the NSKS as a posttest. The NSKS is purported to be an objective measure of a respondent's understanding of the nature of scientific knowledge. The instrument contains 48 statements with a Likert scale format containing five choices (i.e., strongly agree, agree, neutral, disagree, strongly disagree). In addition to a total score, the NSKS yields scores on each of six additive subscales. The subscales are as follows: 1) amoral (scientific knowledge itself cannot be judged as good or bad), 2) creative (scientific knowledge is partially a product of human creative imagination), 3) developmental (scientific knowledge is tentative), 4) parsimonious (scientific knowledge attempts to achieve simplicity of explanation as opposed to complexity), 5) testable (scientific knowledge is capable of empirical test) and 6) unified (the specialized sciences contribute to an interrelated network of laws, theories, and concepts).

Since the strength of any research rests heavily upon the "trustworthiness" of the assessment instruments, coefficient alpha reliabilities (Nunnally, 1967) were calculated for each subscale and the Overall score on both the NSKS pretest and posttest. The reliability coefficients for the students' pretest ranged from a minimum of $r = 0.66$ (Parsimonious subscale) to a maximum of $r =$

0.77 (Overall scale) while the teachers' coefficients ranged from a minimum of r = 0.70 (Parsimonious subscale) to a maximum of r = 0.93 (Overall scale). For the posttest, students' reliability coefficients ranged from a minimum of r = 0.70 (Parsimonious subscale) to a maximum of r = 0.84 (Overall scale) while the teachers' coefficients ranged from a minimum of r = 0.72 (Parsimonious subscale) to a maximum of r = 0.92 (Overall scale).

Changes in students' conceptions of the nature of science were measured by calculating differences between NSKS pre- and posttest scores (i.e., posttest minus pretest). Class means for these "change" scores were standardized and used for the rank ordering of classes with respect to the magnitude and direction (i.e., toward or away from the teacher's conception) of students' conceptual changes. The six classes exhibiting the greatest magnitude of change were designated as "high" and those six exhibiting the least change were designated as "low." The remaining six classes were classified as "medium" but were not used for subsequent analysis. Since the students in a particular class might simultaneously exhibit large conceptual changes on one of the NSKS subscales but small changes on another subscale, the aforementioned classification approach was performed for each of the NSKS scales (i.e., Overall and the six subscales). The results of this classification are presented in Table 1.

Intensive qualitative classroom observations were conducted in each of the 18 classrooms between NSKS pre- and posttest administrations. The researcher was unaware of the NSKS pretest performance of students and teachers while making classroom observations. During each observation, an attempt was made to record all teacher and student verbalizations, chalkboard notes, handouts, assignments, teacher mannerisms, nonverbal cues, and classroom physical plan. A total of three observations, spanning the entire fall semester, were conducted for each teacher/class. The set of field notes collected for each teacher/class (i.e., approximately 90 pages) constituted the "data set" for that particular teacher/class. Thus, 18 individual "data sets" resulted from classroom observations.

The researcher qualitatively constrasted the "data sets" of teachers/classes which were classified as "high" on at least four of the seven NSKS scales with those "data sets" of teachers/classes classified as "low" on at least four of the seven NSKS scales. This scheme resulted in the systematic comparison of eight teachers/classes (i.e., four "high" and four "low"). Those classroom variables identified as differentiating between the divergent "data sets" were operationally defined and examples of how each variable was manifest in the classroom were recorded. A complete list of these derived variables (with definitions) is found in Table 2.

Twenty-one independent "raters" (with expertise in the study of teaching, science education, and/or science content) were used to test the ability of each qualitatively derived classroom variable to statistically discriminate between "high" and "low" teachers/classes. Each rater was provided with a training manual designed to familiarize him/her with the classroom variables. Then, inter-rater reliability was determined by having all raters compare the same two "data sets" using the classroom comparison instrument presented in Figure 1.

Figure 1
Classroom Comparison Instrument

Name of Rater ____________________ Date ____________________

Classrooms Compared __________ X __________

Classrom Variables

1. ____________________ / / / / / / / / / / / / Less ... More

2. ____________________ / / / / / / / / / / / / Less ... More

etc.

On this instrument, specific ratings identify which teacher/class exhibits "more" of a given classroom variable and which teacher/class is believed to exhibit "less." Inter-rater agreement was calculated for each classroom variable, with a criterion value of 0.75 required for acceptance. Inter-rater agreement ranged from 0.75 to 1.00 for the variables meeting criterion. Only one of the 44 original variables (i.e., Periodic Review) had to be excluded from further analysis because it failed to meet criterion.

Following the establishment of inter-rater reliability, each rater compared "data sets" (i.e., complete sets of field notes from individual teachers/classes) in the same manner as had been done for the reliability check. A 6 X 6 matrix was constructed by opposing those six teachers/classes categorized as "high" and those six categorized as "low" for each of the seven NSKS scales (i.e., Overall scales and six subscales). Each of the 21 raters was randomly assigned to perform eight "high/low" comparisons. Thus, a total of 168 comparisons was performed (24 for each NSKS scale) with each individual rater making at least one comparison for each scale.

The teacher/class comparisons produced data which may be perceived as a series of binomial variables, since in each instance of comparison for a particular classroom variable, a rater determined which teacher/class evidenced "more" of a particular variable and which evidenced "less." Thus, the discriminatory significance of each qualitatively derived classroom variable could be statistically tested using the binomial test as described by Kerlinger (1965, pp. 260-263).

The results of these analyses served as an independent quantitative test indicating which of the classroom variables were significantly related to changes in students' conceptions of the nature of science. Each of the 44 derived variables was subjected to a non-directional binomial test with a level of significance of 0.05.

Results

The primary results have been organized with respect to the salient features of the research design.

Teacher/Class Classification

The mean changes (i.e., posttest minus pretest) in students' NSKS scores were standardized and used to rank order individual classes. The six classes exhibiting the greatest change were designated as "high" and those six exhibiting the least change were designated as "low." Classes were classified in this manner for the NSKS Overall scale and the six subscales. The specific results of classroom classification are presented in Table 1.

TABLE 1
Classification of Teachers/Class With Respect to Standardized Student NSKS Score Changes

Overall Scale	Standardized Student "Change" Scores: Mean Change/S.D. (Teacher/Class Identification Code) Amoral Subscale	Creative Subscale	Developmental Subscale	Parsimonious Subscale	Testable Subscale	Unified Subscale
			High			
.832(R)	.550(O)	.684(R)	.698(O)	.881(H)	.555(G)	.965(Q)
.729(F)	.508(R)	.416(L)	.539(E)	.577(E)	.499(N)	.900(R)
.654(L)	.451(K)	.323(H)	.350(R)	.505(L)	.385(K)	.636(N)
.604(H)	.430(P)	.310(B)	.313(H)	.462(N)	.318(H)	.469(M)
.562(N)	.398(I)	.268(N)	.275(F)	.263(R)	.283(R)	.468(L)
.432(P)	.390(E)	.239(K)	.159(C)	.176(B)	.254(J)	.456(P)
			Medium			
.404(K)	.355(F)	.186(A)	.151(M)	.134(O)	.221(F)	.433(E)
.360(F)	.348(A)	.186(P)	.084(N)	.130(G)	.214(L)	.397(D)
.315(Q)	.288(M)	.156(E)	.053(B)	.099(D)	.150)B)	.235(C)
.235(M)	.273(N)	.139(M)	.010(K)	.049(K)	.140(A)	.206(G)
.222(B)	.217(L)	.133(I)	-.036(G)	.049(M)	.078(P)	.188(I)
.118(C)	.205)H)	.064(C)	-.046(I)	0 (A)	.057(I)	.043(K)
			Low			
.088(I)	.197(B)	.013(Q)	-.134(Q)	-.052(P)	.055(D)	0 (J)
.030(A)	.184(C)	-.138(D)	-.155(D)	-.094(F)	-.064(E)	-.034(F)
-.054(G)	.023(D)	-.219(F)	-.245(J)	-.161(C)	-.102(C)	-.096(H)
-.231(D)	-.023(G)	-.353(J)	-.274(A)	-.175(I)	-.182(M)	-.191(B)
-.362(J)	-.183(J)	-.528(O)	-.310(P)	-.352(J)	-.256(F)	-.238(O)
-.479(O)	-.615(Q)	-.601(G)	-.327(L)	-.362(O)	-.307(O)	-.341(A)

Note: The letters within the parentheses are the identification codes used to disquise the identity of each teacher/class

Derivation of Classroom Variables

Qualitative comparisons between contrasting data sets" (i.e., "high" vs. "low" teachers/classes) yielded the 44 classroom variables presented in Table 2. Each of the variables has been placed along a behavioral continuum. That is, the parenthetical portion of each variable definition represents one end of the continuum while the alternative represents the other end. Defining classroom variables in this manner provided the most valid depiction of the classrooms being studied and, therefore, facilitated quantitative class comparisons. The variable definitions are necessarily summarized from those actually given to the raters. A complete copy of the "Rater Manual" can be obtained from the author.

TABLE 2
Derived Classroom Variables

1. ANECDOTAL (TG) - Teacher uses (does not use) stories, analogies & examples to illustrate concepts
2. DYNAMIC (TG) - Teacher's presentation is (is not) energetic & theatrical with good voice inflections
3. ROTE MEMORY/RECALL (TG) - Material is (is not) presented at the factual or knowledge level
4. LECTURING (TG) - Teacher talk does (does not) monopolize class time with little student involvement
5. FREQUENT QUESTIONING (TG) - Teacher asks (does not ask) frequent questions
6. FRAGMENTED (TG) - Teacher's presentation is (is not) "free-flowing" and logically sequential
7. HIGHER LEVEL QUESTIONS (TG) - Higher level questions (Bloom's Taxonomy) are (are not) used frequently
8. INSTRUCTIONAL DIGRESSION (TG) - Topics peripherally related to main concept are (are not) pursued
9. PACING (TG) - Teacher does (does not) continually assess class understanding and adjusts pace accordingly
10. PERIODIC REVIEW (TG) - Class time is (is not) used to review/drill students on previously presented material
11. PREDICTABLE (TG) - Mode of presentation is (is not) inflexible irrespective of content
12. PROBLEM SOLVING (TG) - Open ended questions and/or discrepant events are (are not) used
13. RECEPTIVE (TG) - Teacher is (is not) receptive to student-initiated questions
14. RUSHING (TG) - Teacher does (does not) attempt to quickly cover a predetermined amount of material
15. SEAT WORK (TG) - Class time is (is not) allocated for written exercises or textbook reading
16. PROBING (TG) - Follow-up questions to student responses are (are not) used
17. SUPPORTIVE (TG) - Positive encouragement is (is not) often used
18. HUMOR (TG) - Teacher does (does not) interject jokes and/or humorous histrionics during instructional presentation
19. VARIETY OF MEDIA (TG) - Diverse instructional materials are (are not) used in presentation of content

TABLE 2
Derived Classroom Variables (continued)

20. AMORAL (TC) - Scientific knowledge is (is not) prsented as amoral
21. ANTHROPOMORPHIC LANGUAGE (TC) - Anthropomorphic language is (is not) used and accepted by the teacher
22. ARBITRARY CONSTRUCTS (TC) - Arbitrary nature and utility of scientific constructs are (are not) stressed
23. CREATIVITY (TC) - Scientific knowledge is (is not) presented as a product of human imagination and creativity
24. DEVELOPMENTAL (TC) - Scientific knowledge is (is not) presented as being tentative
25. FALLIBILITY (TC) - Teacher does (does not) admit uncertainty with respect to content
26. LANGUAGE ACCURACY (TC) - Exact definitions of terminology are (are not) stressed
27. MISINFORMATION (TC) - Teacher does (does not) present misinformation
28. MORAL/ETHICAL IMPLICATIONS (TC) - Moral & ethical implications created by science are (are not) emphasized
29. PARSIMONY (TC) - Scientific knowledge is (is not) presented as being comprehensive as opposed to specific
30. QUANTITY OF MATERIAL (TC) - An inordinately large amount of subject matter is (is not) presented
31. RELEVANCY (TC) - Practical nature of subject matter is (is not) emphasized
32. SUPERFICIALITY (TC) - Teacher's explanations of phenomena are correct but inadequate
33. TESTABLE (TC) - The importance of empirical validation of subject matter is (is not) stressed
34. UNIFIED (TC) - The interrelationship of various science disciplines is (is not) emphasized
35. DEMEANOR (TA) - The teacher is (is not) pleasant
36. IMPERSONAL (TA) - The teacher does (does not) attempt to socialize with students before or after class
37. NON-INSTRUCTIONAL DIGRESSIONS (TA) - The teacher does (does not) tell stories totally unrelated to content being presented
38. ACTIVE ENGAGEMENT (S) - Students are (are not) actively participating in lesson
39. ATTENTIVE (S) - Students are (are not) on task for most of the class period
40. UNSOLICITED QUESTIONS (S) - Students ask (do not ask) unsolicited questions
41. DISCIPLINE (C) - Classroom atmosphere is (is not) highly structured and discipline oriented
42. DOWN TIME (C) - Class time is (is not) often characterized by students waiting for next activity
43. LOW ANXIETY (C) - Classroom atmosphere is (is not) comfortable with little anxiety
44. RAPPORT (C) - Teacher and students do (do not) socialize and interact in a friendly manner

Variable categories: TG: Teacher's general instructional approach; TC: Teacher's content-specific characteristics; TA: Teacher's non-instructional characteristics; S: Student characteristics; C: Classroom atmosphere

Quantitative Analysis of Classroom Variables

The ability of the qualitatively derived classroom variables to statistically discriminate between "high" and "low' teachers/classes was assessed using the procedure described in the Method section of this paper.

Since raters were only asked to describe which teacher/class exhibited "more" of a particular variable, finding that a variable discriminates statistically between the "high" and "low" groups does not necessarily mean that the particular variable was present in one group and absent in the other. Such a finding may simply indicate that the variable in question was present to a greater degree in one group than the other. In either case, those classroom variables found to statistically differentiate between the "high" and "low" teachers/classes are clearly related to changes in students' conceptions of the nature of science. The specific quality of this relationship may be noted by observing with which group (i.e., "high" or "low") each variable is most commonly associated. The results of the aforementioned analysis are presented in Table 3.

TABLE 3

Results of Paired Comparisons

Classroom Variable	Overall Scale	Amoral Subscale	Creative Subscale	Developmental Subscale	Parsimonious Subscale	Testable Subscale	Unified Subscale
1. Anecdotal	H	H	H	H	H		H
2. Dynamic	H		H	H	H	H	H
3. Emphasis on rote memory/recall	L		L	L	L		L
4. Extended lecturing	L		L		L	L	L
5. Frequent questioning	H		H	H	H	H	H
6. Fragmented							
7. Higher cognitive level quetions	H	H	H	H	H	H	H
8. Instructional digression	H	H	H	H	H	H	H
9. Pacing	H						H
10. Periodic review					H		
11. Predictable	L	L	L		L	H	
12. Problem solving	H	H	H	H	H	H	H
13. Receptive to unsolicited questions	H	H	H	H	H	H	H
14. Rushing				L			
15. Seat work	L	L	L	L	L	L	L
16. Sequential probing	H	H	H	H	H	H	H
17. Supportive	H	H	H	H	H	H	H
18. Use of humor	H	H	H	H	H	H	H
19. Variety of instructional media	H	H	H	H	H	H	
20. Amoral		L					

H = $p < .05$ and more common to "High" group
L = $p < .05$ and more common to "Low" group

TABLE 3

Results of Paired Comparisons (continued)

Classroom Variable	Overall Scale	Amoral Subscale	Creative Subscale	Developmental Subscale	Parsimonious Subscale	Testable Subscale	Unified Subscale
21. Anthropomorphic language							
22. Arbitrary constructs	H		H		H	L	
23. Creativity			H	H	H		H
24. Developmental	H		H	H	H	H	H
25. Fallibility	H	H	H		H	H	
26. Language accuracy	H	H	H	H	H	H	H
27. Misinformation	L		L		L	L	L
28. Moral & ethical implications	H	H	H	H	H	H	H
29. Parismony							H
30. Quantity of material	H				L	H	H
31. Relevancy	H	H	H	H	H	H	H
32. Superficiality	L		L		L	L	L
33. Testable	H	H	H	H	H	H	H
34. Unified					H	H	L
35. Demeanor	H	H	H	H	H	H	H
36. Impersonal	L	L	L	L	L	L	L
37. Non-instructional digression	H	H	H				H
38. Active engagement	H	H	H	H	L	H	H
39. Attentive	H	H	H	H	L	H	H
40. Unsolicited questions	H	H	H	H	H		H
41. Discipline							
42. Down time	L	L	L		L	L	L
43. Low anxiety	H	H	H	H	H	H	H
44. Rapport	H	H	H	H	H	H	H

H = $p < .05$ and more common to "High" group
L = $p < .05$ and more common to "Low" group

Discussion

Forty-one of the original 44 classroom variables were found to discriminate statistically between the "high" and "low" groups of teachers/classes on at least one NSKS scale. Since the teachers in this study typically possessed views consistent with those of each NSKS scale, students of the "high" classes exhibited conceptual changes compatable with the amoral, creative, developmental, testable, parsimonious, and unified viewpoints of the nature of science.

Generic Classroom Variables

Thirty of the classroom variables achieved statistical significance on at least four of the six NSKS subscales in addition to the Overall scale. These variables were considered to be "generic" by virtue of their relatively pervasive importance. In the following discussion, the reader is advised to view the variables discussed as a network of factors which interact to create the instructional milieu of each classroom.

The teachers/classes of the "high" group were typically more pleasant and supportive than those of the "low" group. The telling of Anecdotes (1), Use of Humor (18), and Instructional Digressions (8) used by the teachers in the "high" group appeared to create a warm, friendly atmosphere. In addition, the teachers of the "high" group were more open to student input, as evidenced by the significance of the Supportive (17) and Receptive to Unsolicited Questions (13) variables. Although it is easy to see how a warm and supportive atmosphere would be desirable in any classroom, such an atmosphere does not necessarily contribute to learning. Students must become excited about the material being presented. Their interest and curiosity must be piqued, for a warm and supportive climate might simply represent a non-threatening environment in which the student feels no need to expend any effort. The Dynamic (2) nature of the teachers' presentations and the use of a Variety of Instructional Media (19) appeared to have accomplished this task. Furthermore, the related variables of Emphasis on Rote Memory/Recall (3), Extended Lecturing (4), increased Seat Work (15), and Down Time (42), were more common to the "low" group. Certainly, extended periods of inactivity and the completion of worksheets coupled with a major emphasis on memorization or "facts" would detract from the "high-energy" atmosphere created by a dynamic teacher who uses multi-media presentations.

The foregoing variables may be considered as prerequisite variables since they facilitate learning when present to a large extent and inhibit student progress when absent or present to a lesser extent. In addition, teachers in the "high" group tended to ask questions more frequently, as indicated by the statistical significance of the Frequent Questioning (5) variable. The questions tended to be of a Higher Cognitive Level (7) and Problem Solving (12) in nature. Consistent with the problem-solving mode of the "high" group, the teachers of these classes sequentially Probed (16) student responses. If one views questioning as a prerequisite classroom variable, its beneficial effects on student involvement and attention are obvious. General support for questioning in this regard has been well established by Brophy and Evertson (1976) and others. However, Frequent Questioning (5), Higher Cognitive Level Questions (7), Problem Solving (2), and Sequential Probing (16) are all related to the more general classroom dimension of teacher-student interactions which cause students to think about (and not just memorize) subject matter. An analysis of the actual interactive sequences recorded in the field notes revealed numerous instances in which such interactions led to discussions directly related to one or more of the NSKS scales. Therefore, the various questioning variables may be viewed as directly related to changes in students' conceptions in addition to their role as prerequisite classroom variables.

The teachers of the "high" group related subject matter to the students' personal lives more commonly than those of the "low" group, as indicated by the significance of Moral and Ethical Implications (28) and Relevancy (31). However, it is important to note that this stress on relevancy did not compromise the presentation of subject matter. The emphasis on depth and accuracy of content within the "high" group of teachers/classes is clearly illustrated by the increased attention given to Fallibility (25) and Language Accuracy (26) while Misinformation (27) and Superficiality of Explanations (32) were more typical of the "low" group. In addition, the Developmental (24) and Testable (33) variables were more common to the "high" group. Since each of these latter variables is specifically related to NSKS subscales, their association to the students' conceptual changes is direct.

Finally, variables such as Demeanor (35), Active Engagement (38), Attentive (39), Unsolicited Questions (40), Low Anxiety (43), and Rapport (44) were more common to the "high" group while Impersonal (36) was more typical of the "low" group. The influence of these variables should be considered as prerequisite with respect to changes in students' conceptions.

In summary, irrespective of NSKS scale, the classes exhibiting the largest conceptual changes were more pleasant, supportive, and on-task, with students expected to think analytically about the subject matter presented.

Scale-Specific Variables

Eleven classroom variables were considered to be "scale-specific" by virtue of their statistical significance on a limited number (i.e., less than four) of the NSKS scales. The most intriguing findings are reported here.

Specific comments supporting the Amoral (20) nature of scientific knowledge were more typical of the "low" teachers/classes. Since the "high" group exhibited the greatest student change toward a belief in the amoral nature of science, this finding is contrary to what one might have expected. However, the examination of individual class transcripts provided a viable explanation.

Subsequent to a discussion concerning the "necessity" of a large deer-kill by hunters, the following teacher-student interaction was noted:

Teacher: "Now, as John was saying earlier, many hunters think it is more humane to kill the deer because it is a quick death as opposed to disease or starvation. But, that's a topic of personal preference. We don't want to get into morals in science class."

John: (calling out emphatically): "But you have to!!"

Teacher: "No we don't. It's a matter of personal preference, not science."

In the previous instructional sequence the teacher has clearly implied the inappropriateness of discussing moral issues in class. Interestingly, the students in this particular class moved toward a more moral viewpoint and not the expected amoral viewpoint. However, the debate concerning the "humaneness" of hunting is a highly controversial issue and the teacher's response to the student's emotional beliefs was dogmatic at best. In view of the dynamics of the situation, it is understandable how a student may resist the teacher's "opinion" and actually strengthen his/her own viewpoint.

Explicit comments concerning the Unified (34) nature of scientific knowledge were more common to teachers/classes in the "low" group on the Unified subscale. Once again, this observation is counterintuitive. That is, how could statements endorsing a Unified (34) viewpoint of science exert an influence other than the enhancement of the belief that the various sciences are interrelated? Analysis of individual class transcripts revealed that explicit references to the Unified (34) nature of science commonly occurred during the unit on biochemistry. The following excerpt from a class transcript was observed:

Teacher: "First, let's get down some notes so you can all be squared away with what we'll be going to do in this unit on chemistry. Now (pause) this is not a chemistry course you're in. It's biology. So why are we doing chemistry?"

The teacher pauses for about 5 seconds while he looks around the room. He continues with added emphasis:

Teacher: "I'll tell you why. It's because there is nothing, absolutely nothing, that we have talked about or will talk about in biology that isn't based on chemistry. Without a knowledge of chemistry, it is difficult to explain the processes of biology. So, when I hear: 'Why do we have to study atoms?' (said with slow pace and in a deep voice), I get real angry . . . ."

This teacher's soliloquy actually continued for an additional three minutes. It is unfortunate, but the "vignette" presented above was more the norm than the exception. Perhaps, it may be speculated, that the students listened to the teacher's initial comments and then "tuned-out" the all too familiar classroom sermon. Such a scenario would explain why the Unified (34) classroom variable wasmost commonly associated with the "low" teachers/classes.

It is extremely interesting to note that the six biology teachers of the "low" group for the Unified subscale were all teaching at least one section of chemistry while those of the "high" group were teaching biology exclusively.

Discussion of the Arbitrary Constructs (22) used in science were more common to the "high" group (although not always significantly so) for all but one NSKS scale. Interestingly, references to Arbitrary Constructs (22) were actually more common to the "low" group of teachers/classes on the Testable subscale. When one considers the apparent contradiction between "tested" knowledge and "arbitrary" knowledge the findings here are understandable. However, this inverse relationship between the Arbitrary Constructs (22) variable and the Testable subscale is disconcerting at best. Certainly, students need to understand the importance of arbitrary constructs to science as well as the necessity of empirical support for scientific knowledge. It appears from the results here that a more diligent attempt at separating useful arbitrary constructs (e.g., taxonomic classification) from experimentally derived knowledge is necessary if we expect our students to understand the value of each of these concepts.

The "scale-specific" classroom variables presented thus far were chosen for discussion because of the unanticipated, and seemingly contradictory, findings with which they were associated. However, the overwhelming majority of "scale-specific" variables did not produce such intrigue. For example, Creativity (23) was significantly more common to the "high" group on the Developmental subscale. The relationship of Creativity (23) to students' viewpoints on the tentativeness of scientific knowledge is direct. Indeed, it is the creative and imaginative aspect of scientific knowledge which implies and results in its tentative nature. Alternatively, if one does not agree that creativity has a place in scientific endeavors, then such an individual is also apt to believe scientific knowledge to be absolute, unwavering "truth."

Implications for Science Education

Although teachers have been berated in the past for failure to promote adequate student conceptions of science (Miller, 1963) and are currently being strongly urged to reverse the situation (NSTA, 1982), they have not been offered any reserach-based advice on how to accomplish such an important goal of science education. This investigation identifies those classroom variables that can be tested more thoroughly in future studies to ascertain their role in establishing students' conceptions of the nature of science. In short, each variable identified serves as an hypothesis which needs to be tested using a structured observation coding system. However, a recent investigation using an experimental design supports the findings obtained here (Haukoos & Penick, 1983).

A rather provocative issue surfaces when one considers the current emphasis on improving the scientific literacy of our secondary school students. The scientifically literate individual possesses an in-depth understanding of scientific facts, concepts, and theories as well as a clear understanding of the nature of science (Collette & Chiappetta, 1984). Soar and Soar (1972) have previously commented on the positive effects of drill, teacher direction, narrow subject matter focus, and emphasis on lower-level understandings with respect to "simple-concrete" student knowledge. Such knowledge is quite consistent with the "content" dimension of scientific literacy. Unfortunately, attention to drill and lower-level understandings were found by Soar and Soar (1972) to be detrimental to students' "complex-abstract" knowledge. Indeed, emphasis on rote memory/recall was more common to the "low" group of teachers/classes in this investigation. Alternatively, stress on higher-level understandings and inquiry was strongly associated with changes in students' conceptions of the nature of science. The current educational atmosphere is stressing both the "content knowledge" and the more abstract "nature of science" aspects of scientific literacy. However, teachers are often evaluated on the basis of students' scores on achievement tests which predominantly measure lower-level knowledge. Therefore, science teachers are being urged, in part, to promote gains in students' "abstract" knowledge (i.e., the nature of science) while they are being evaluated on measures of "simple-concrete" knowledge. Since apparently different teaching techniques are optimal for each student outcome, the plea for increased student scientific literacy may be asking for the completion of an impossible task. At the least, a more balanced treatment of "factual" content and the philosophy of science is needed in both curriculum development and instruments of summative evaluation if the goal of scientific literacy is to be achieved.

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