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ABSTRACT

Presented are the results documenting the proof-of-concept effectiveness of an 8-day afterschool professional development program through which secondary science teachers learned to implement an instructional method using historical cases in biology to teach nature of science concepts. Results of the study using a variety of quantitative and qualitative data sources confirmed that the prototype model was feasible for use by secondary teachers in biology to address nature of science concepts, and that the design components of the 8-day professional development program were effective in developing the required knowledge and skills, providing the support necessary for teachers to implement the model successfully in secondary biology classrooms. In addition, participation in the project and use of the historical cases model were found to enhance teachers' own understanding of key nature of science concepts relative to the limited understanding displayed by comparable control teachers. Discussion of the findings included the identification of areas for future development and research involving use of the historical cases model. (Contains 19 references.) (Author/ASK)

USING HISTORICAL CASES TO CHANGE TEACHERSſ UNDERSTANDINGS AND PRACTICES RELATED TO THE NATURE OF SCIENCE [1]

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Abstract

Presented are the results documenting the proof-of-concept effectiveness of an 8-day afterschool professional development program through which secondary science teachers learned to implement an instructional model using historical cases in biology to teach nature of science concepts. Results of the study using a variety of quantitative and qualitative data sources confirmed that the prototype model was feasible for use by secondary teachers in biology to address nature of science concepts and that the design components of the 8-day professional development program were effective in developing the required knowledge and skills and providing the support necessary for teachers to implement the model successfully in secondary biology classrooms. In addition, participation in the project and use of the historical cases model were found to enhance teachersſ own understanding of key nature of science concepts relative to the limited understanding displayed by comparable control teachers. Discussion of the findings included the identification of areas for future development and research involving use of the historical cases model.

Despite the fact that understanding the nature of science has been a continuing curricular goal, science education research consistently has found that teachers possess neither adequate conceptions nor the instructional strategies necessary to teach it effectively (Lederman, Wade, & Bell, 1998). In fact, the nature of science has been considered an important curriculum issue that largely has been ignored in classrooms and misrepresented in textbooks (McComas, Clough, & Almazroa, 1998). At the same time, in those limited cases in which the nature of science has been a component in science content courses, general strategies based upon the stories of scientists or historical events in science have been used as an instructional framework (Bentley & Fleury, 1998). Among these, one specific historical approach has been to replicate classical experiments, a strategy particularly common in physics (Seroglou, Koumaras, & Tselfes, 1998; Lawrenz & Kipnis, 1990). Another has been to use examples from history to illustrate the role of theories as a basis for explanations and explorations (Rudolph & Stewart, 1998; Scharmann & Harris, 1992). A third strategy has focused on historical vignettes that attempt to provoke students into critically re-examining their ideas about the nature of scientific knowledge (Roach & Wandersee, 1995; Chan, 1999). Although promising, none of these strategies has been utilized within a curricular planning and implementation framework that comprehensively integrates nature of science concepts within the context of science knowledge being taught by using a professional development design feasible for secondary science teachers.

The present study incorporated the use of historical cases in the proof-of-concept exploration of a model that integrates knowledge of the nature of science with science content knowledge, reflecting a perspective recently advocated by Shavelson, Copeland, Baxter, Decker, & Ruiz-Primo (1994) in the professional development literature. In doing so, the model addresses "the special knowledge of curriculum, learning, teaching" which, according to the National Research Council (1996, p. 62), distinguishes the science knowledge of teachers from that of scientists. Within this context, the study explored the feasibility of the historical cases model in the real-life setting of secondary biology instruction. In targeting a form of a model replicable with teachers in other settings, the development process specifically reflected practical considerations that include the limitations of teachersſ time, the scarcity of resources available to teachers, and the specific curriculum constraints under which teachers work. And, in doing so, the historical cases model supports the integration of nature of science concepts into existing science curriculum frameworks by enabling teachers to adhere to the "less is more" philosophy advocated by the National Science Teachers Association (1992) and the National Research Council (1996).

[1] Paper presented to the Annual Meeting of the National Association for Research in Science Teaching, Boston, MA, April, 1999.

A Model for Using Historical Cases to Teach the Nature of Science

The rationale underlying the historical cases model used in the study was that a more meaningful understanding of nature of science concepts would result from their being embedded in a historical setting contextualized by the core biology concepts being taught rather than their being taught separately in a "context-free" fashion. More specifically, the model consisted of two complementary partsóa planning component and an implementation componentó as described below.

Planning Component of the Historical Cases Model

The planning component of the model consists of the following general steps:

1. Teachers develop a curriculum scope and sequence specifying the concepts to be taught in biology instruction for the semester or school year.

2. Teachers identify the nature of science concepts to be addressed during the semester/school year.

3. Teachers conduct historical research for each of the specific biology concepts that serve as a context for the nature of science concepts to be addressed, using a template of descriptors (see Table 1) to determine the appropriate scope, sequence, and frequency of nature of science to be incorporated into the content units.

4. Teachers prepare resources to use with their classes and make final adjustments to the scope and sequence as appropriate.

Implementation Component of the Historical Cases Model

The implementation component of the model consists of the following general steps:

1. At the appropriate instructional time (according to the scope and sequence), teachers augment teaching of biology concepts with a historical enhancement regarding the past development of the concept (or concepts) through a series of events over time. (A "historical case" in this context involves the work of many scientists over time focusing on the evolution of a scientific idea, not just one event.)

2. Within that historical context, teachers have students use a template (see Table 1) as a tool to identify nature of science concepts that are illustrated through the historical studies.

3. During the course of the year, teachers emphasize the reoccurrence of nature of science concepts in a variety of historical cases related to different biology concepts.

4. Upon completion, teachers continue with the next topic(s) in the biology scope and sequence.

In the present study, the planning component of the model, including the necessary research, was accomplished over a four month period through an after-school professional development program for biology teachers (described below), while the implementation component (along with teachersſ responses) provided the major focus for determining the feasibility of the historical cases model.

Table 1

Template of Descriptors for Nature of Science Concepts

11. that theories are broad explanations which are made up of related hypotheses that have gained substantial support?

Design Components of the Professional Development Program for the Historical Cases Model

The major consideration that influenced the design of the professional development program was the use of the general criteria for effective professional development programs (Fullan & Steigelbauer, 1991; Sparks & Loucks-Horsley, 1990) as a guide for preparing teachers to use instructional strategies to address nature of science content. The criteria for exemplary practices in professional development included: (a) recognition of teachers' time limitations in scheduling sessions; (b) provision of opportunities for teachers to develop instructional materials for use in their classrooms, using available resources; (c) modeling appropriate teaching strategies; and (d) encouragement through classroom visits by the professional development instructor. Key elements in the design of the professional development program used in the study are summarized below.

General Schedule and Timeline

From the considerations mentioned above, a detailed professional development plan was developed to focus on a narrow range of issues, conforming to the time restrictions necessarily imposed on the after-school project. Specifically, the nature of science instructional professional development program consisted of eight two-hour sessions scheduled over a four-month period during the spring semester. The schedule also included a four-week interval between Session 7 and Session 8 to allow for classroom visits by the instructor during implementation efforts.

Topic Selection

The scope of the content for the participating teachers focused on the most critical aspects (see Table 1) of the nature of science, taking into account common misconceptions, topics appropriately addressed through historical events, and curriculum constraints. From these considerations, the following topics were chosen: scientific methodologies; tentativeness of scientific knowledge, including the public nature of science (the role of the scientific community in confirmation/rejection of ideas) and the historical development of science; and the nature and role of theories, including theories as inventions, the role of theories in limiting objectivity of scientists, and distinctions between facts, hypotheses, theories, and laws.

Teacher Background Information

Because it was unrealistic to expect teachers to develop profound understandings about the nature of science from only a limited exposure to case histories; the project exposed teachers to resource materials (e.g., readings) and discussions related to the selected nature of science issues before the teachers began their own research into historical cases in biology. In essence, the historical studies in biology provided evidence to confirm or refute generalizations from the current literature on the history and philosophy of science, while emphasizing that views on the nature of science themselves are also tentative.

Use of a Model Demonstration Lesson

Addressing the nature of science through historical cases was a new approach for the teachers. Therefore, the instructor presented a model lesson to illustrate the connection of nature of science issues with biology content. With cell theory as the biology content focus, the model lesson used the strategy of a dramatization with a narrator and characters from history whose work contributed to our modern ideas about cells as the structural and functional basis of organisms.

Collaborative Teacher Development of Benchmark Instructional Units

An important component of the project design was the development of classroom instructional units by the teachers. Applying Little's (1993) principle of offering meaningful intellectual engagement with ideas, with materials, and with colleagues, this task served two key purposesóreinforcing the teachers' learning and increasing the likelihood that ideas from the workshop were transferable to classroom practice. Within this component, the teacher participants were formed two groups of four, each of which focused on a single biology content topic. One group chose "evolution theories" and the second "circulatory/respiratory systems" as the biology content basis into which they embedded nature of science issues.

During the research and development process in constructing the model lessons, the teachers identified key individuals (both early philosopher-scientists and modern experimental scientists) and then noted their methodologies, their findings, their interactions with each other (or with the written records of other scientists), the reaction of society, and the influence of the prevailing scientific paradigms. Using nature of science issues as a framework as defined by the template shown in Table 1, teachers were able to connect the historical accounts as evidence to support or refute contemporary views of the nature of science. Once they determined which issues could appropriately be addressed in the context of history, they developed instructional strategies to involve their students in making connections.

Research Questions

The purpose of the study was to design a prototype model for using historical cases to embed nature of science concepts within science instruction and then to test the feasibility of the model with secondary biology teachers. In doing so, reflecting its importance in the literature, an additional focus of the study was whether teachersí implementation of the model also would enhance their own understanding of key nature of science concepts. The specific research questions addressed in the study were as follows:

1. *Was the prototype model feasible for teacher utilization in teaching nature of science concepts using historical cases within biology instruction?*

2. *Was the associated after-school staff development program (8 sessions over four months) supporting the implementation of the model effective in developing the teacher knowledge and skills necessary for implementing the model?*

3. *Did preparation and use of the historical case-based model enhance teachersí own understanding of key nature of science concepts?*

Thus, in addressing these questions, the goal of the study was to demonstrate the feasibility of the model and associated training program in a proof-of-concept sense.

Method

Participants

Treatment and control participants were inservice and preservice high school biology teachers from five high schools located in a non-urban school system in the southeastern United Stares. For purposes of the study, the five high schools were blocked into demographically comparable groups and then, within these groups, randomly designated as treatment or control schools. The biology teachers (n=8) from the treatment schools consisted of five regular teachers and three preservice teacher interns completing a year-long practice-teaching experience. They included all of the teachers who volunteered for participation in an 8-session after school program during the spring semester (and other activities) required by the study in response to a general letter sent to all biology teachers in the treatment schools. The control teachers (n=8) were selected from biology teachers in the control schools who indicated in a response to a letter they would be willing to participate in the data-gathering parts of the study. The group of control teachers was selected randomly from their schools with the constraint that, like the treatment group, it included five regular and three preservice teachers.

All of the teachers were teaching one or more classes of first-year biology using the North Carolina Standard Course of Study in Science as a curriculum guide. In keeping with State requirements, all high schools in the system followed a uniform curriculum for first-year biology students and administered a State-developed *criterion-referenced biology test (with a minor nature of science component) at the end of the school year to all students. None of the participants in either group had previously participated in professional development focusing on the nature of science; nor had any taken an undergraduate or graduate course in either history or philosophy of science.*

Professional Development Program Supporting Biology Teachersſ Implementation of the Model

Table 2 shows the 10 nature of science concepts addressed by teachers in the study and emphasized in the after school program. The selection of the concepts for the study reflected both those recognized in the literature on contemporary views of the nature of science and the "Nature of Science" goals in the North Carolina Standard Course of Study . Teachers applying the model first conducted historical research to trace the scientific development of selected biology concepts or topics. Next, the teachers identified specific instances that illustrated applicable nature of science concepts. In this study, biology teachers implementing the model identified a variety of historical case scenarios to use during their courses in the process of developing curricular plans that insured scope of coverage of the nature of science concepts addressed.

Table 2

Nature of science concepts addressed in the study

Nature of Science Concept	Nature of Science Principle
Public Nature of Science	Most scientific work is a public matter, in which knowledge is shared openly.
Tentativeness of Scientific Knowledge	All scientific knowledge domains are tentative and subject to future revision.
Historical Progression of Science	It is natural that ideas presently accepted by the scientific community may be judged as naive in the future.
Importance of Replication of Studies	Research findings are generally viewed with skepticism until validated through replication.
Role of Theories	Scientific theories play a fundamental role in the work of most scientists.
Objectivity of Scientists	Observations made by scientists are somewhat subjective in that they are dependent on adopted theories.
Theories vs. Laws	No matter how much evidence is amassed in support of a theory, it will not become a scientific law.
Construction of Theories	Just as an architect invents a structural design, a scientist may invent a theory.
Nonnal vs. Revolutionary Science	The work of most scientists is to support, enlarge, or alter existing theories.
Role of the Scientific Community	When there are two competing theories, the better is a matter of consensus among scientists based on critical scrutiny.

After completing the necessary research and curricular planning, teachers implemented the historical cases model within classroom instruction to students using the following general process:

1. Teachers initiated discussion a selected biology concept (preceded by connections to prior instruction).

2. Teachers facilitated student activities that placed the scientific development of the biology concept in a historical perspective.

3. Teachers facilitated the identification by students of nature of science concept(s) that the historical perspective illustrated (within the historical biology context).

4. Teachers facilitated clarifications of the nature of concept(s) illustrated in the form of generalizations about the nature of science.

The afterschool professional development program that prepared teachers to implement the historical cases model consisted of eight sessions specifically designed to support the development of teachersſ lesson plans regarding the nature of science instruction within biology. As part of this process, teachers worked collaboratively in small groups to complete the historical research while developing their individual curricular plans for the school year. Because the model addressed both nature of science issues and biology topics, it was necessary to assemble instructional resource materials in both areas. From the literature on the nature of science, the researcher chose representative articles and excerpts which communicated concisely and clearly the targeted concepts, carefully selecting those writings which were challenging but which were also appropriate for individuals who had had limited exposure to history and philosophy of science. Copies of these materials were provided to the teachers as a basis for discussion. The university library served as an additional teacher resource for books on the history of biology. After the teachers chose specific topics for their instructional units, they also obtained additional library source materials in developing specific curriculum/lesson plans. Although those resources were not available after the workshop, teachers made notes from them for subsequent use in the development of classroom biology materials.

Instruments

Assessing teachersſ understanding of the nature of science . A multipart *Nature of Science Questionnaire* assessed treatment and control teachersſ understanding of each of the 10 the nature of science concepts directly targeted in the training program (see Table 2). First, each of the 10 questionnaire items required teachers to choose between pairs of opposing statements that were either consistent or inconsistent with prevailing views on the nature of science. Since the intent was to contrast traditional with contemporary views of the nature of science, the choices presented required teachers to discriminate which of two opposing statements best represented the selected concept. For example, the sixth item referencing the objectivity of science included these choices: (a) "The observations made and recorded by most scientists are somewhat subjective in that they depend at least in part on the theories that scientists adopt," (b) "Most scientists depend on direct, objective observation more than on previous findings or pre-existing theories," and (c) "no opinion." A three-point scale was used to code the responses as either consistent with a contemporary view of science (3 points), no opinion (2 points), or not consistent with contemporary view of science (1 point). Content validity of the 10 pairs of opposing statements regarding their relevance to the nature of science concepts was verified by a two science education professors using Kerlingerſs (1986) criteria of representativeness and relevance. The contrasting statements associated with each of the 10 nature of science concepts are shown in the Appendix.

The second component of each of the 10 Questionnaire items asked teachers to provide a rationale for their choice using an open-ended response format. The resulting responses were then scored by applying a three-point rubric: strong, consistent with the correct choice (3 points); weak, but with no inconsistent element (2 points); or weak, with at least one inconsistent element (1 point). And, finally, the third component of each Questionnaire item asked teachers to provide an illustrative example in support of their rationale. These examples were then scored as to appropriateness as follows: (a) appropriate-- 3 points, (b) absent-- 2 points, or (c) inappropriate-- 1 point.

The two raters/scorers for the second and third item components were a science education professor and a graduate student in science education, both of whom received training regarding their use of the rubrics through field-testing completed prior to scoring the questionnaires used in the study. The field-test training consisted of having the raters independently score the responses of eight high school science teachers not involved with the study. In scoring the questionnaires, the two raters who had been trained by the researcher to use the scoring rubrics for parts 2 and 3 obtained an inter-rater reliability of 90% degree of agreement across the 160 individual scoring decisions (10 items x 2 scores per item x 8 teachers). As part of the field-testing, the raters also were able to refine their application of the scoring rubrics by resolving inconsistencies through discussion. Subsequently, when same two raters scored the 16 questionnaires completed by the teachers in the present study, their inter-rater reliability (as percent of agreement) was 92%. In addition to the questionnaire directly assessing teachersf understanding of the nature of science, treatment and control teachers also completed an indirect assessment indicator immediately after their nature of science questionnaire. This informal instrument asked teachers to report the degree to which they included nature of science topics in their biology classes during the school year by listing the topics they addressed. The resulting topics reported by the treatment and control teachers were categorized as to "nature of science topic" or "not nature of science topic," thereby providing a measure of teachersf general understanding of nature of science concepts.

Instrumentation documenting teachersf implementation of the model . Three forms of instrumentation were used to monitor the implementation of the model by treatment teachers: (a) *Unit Planning Forms* , (b) *Teacher Logs* , and (c) *Classroom Observation* . The first form of implementation data, *Unit Planning Forms* , were completed by teachers to specify the combinations of nature of science concepts and biology topics they planned to address during the school year. These forms followed a standard free-response format and were analyzed using a two-phase process. In the first phase. the plan contents were categorized by biology topic (either "Evolution" or "Human Systems") and by nature of science concept addressed in their plans. In addition, the degree of inclusion of these concepts (e.g., great, moderate, or little) was determined by examining the teachersf stated objectives, lesson notes, student questions, student assignments, and quizzes or tests in the unit plan in relation to the State Biology Curriculum and the nature of science concepts emphasized in this study. The second phase of analysis consisted of re-reading the plans to determine specifically how teachers used historical cases for their chosen biology topic to teach concepts related to the nature of science. For summary, those strategies were categorized by the specific nature of science concepts addressed in each. The second form of implementation data, *Teacher Logs* , provided a cumulative record of the classroom teaching of biology topics and nature of science concepts during the spring semester of the school year. The logs consisted of notebooks in which teachers recorded the following information each time they addressed a nature of science topic in their teaching: (a) date, (b) biology content topic addressed, and (c) nature of science concept addressed. The teacher logs were analyzed first by compiling a list of all nature of science concepts noted in the logs, along with the biology topics which were being addressed instructionally at that time, and whether or not the nature of science concepts were presented within the context of biology topics (in accordance with the historical cases model). Next, the resulting nature of science concepts identified were grouped into three sub-categories: (a) those having no biology content context, (b) those presented in the context of the biology topics addressed during the workshop series, and (c) those presented in the context of biology topics not addressed during the workshop.

The third form of implementation data, *Direct Classroom Observations* , were intended to provide a "classroom snapshot" of the nature of science topics that treatment teachers chose to address, how they chose to address them (explicitly or implicitly), and details regarding the context in which they were addressed. The observation form used for data collection consisted of a checklist in combination with short elaborative statements that paralleled the planning documents used by teachers. As used in the form, explicit references included direct statements of the identified nature of science concept, while implicit references included statements or phrases which did not state a concept directly but from which inferences could be made about it. *Focus group interview* . In addition, to the more structured forms of data described above, treatment teachers also participated in a structured focus group interview in which the issue addressed was the nature of science as part of teaching science. Compilation of the interview transcript included a multi-layer analysis through which statements were coded into categories created through multiple readings of the responses. The categories imposed on the responses included the following: specific concept mentioned (nature of science in general, nature and role of theories, role of observations, history and philosophy of science), indication of understanding , and incorporation of nature of science topics into instructional plans (present or future).

Design. Statistical Analysis. and Procedure

Table 3 summarizes the overall design of the study. As Table 3 shows, lesson plans were obtained from treatment teachers following the training, as a follow-up to initial versions prepared during the professional development sessions. Project log-books were distributed to treatment teachers at the beginning of the project and kept for the duration of the school year. For the classroom observations, treatment teachers were observed during the spring of the school year. The specific schedule for classroom observations was determined in collaboration with treatment teachers in order to complete them during the month of April, between the last two meetings of the treatment group. During this time, the observer made two visits to each treatment teacherfs classroom. These classroom observations were scheduled to coincide with the prearranged presentation of units developed during the earlier sessions. Finally, in June, at the end of the school year, both the treatment and control teachers completed the *Nature of Science Questionnaire* during a controlled group administration in their home schools. Upon completion of the Questionnaire, treatment teachers participated in the focus-group exploration.

Table 3

Design of the Study

			Dependent Variables		
Group	n	Teacher		Classroom	Nature of Science
		Plans	Logs	Observations	Questionnaire
Treatment[1]	8	Feb.ñ May	Feb.ñ May	April	June
Control	8	N/A	N/A	N/A	June

[1] Lesson plans and teacher logs were completed during and as follow-up to the 8-day program.

All of the quantitative data resulting from the study were coded in electronic form for analysis using *SYSTAT for Windows* (Ver. 7). In general, consistent with the proof-of-concept emphasis of the study, descriptive statistics were presented in tabular form. In the case of comparing treatment and control teachers performance on the *Nature of Science Questionnaire* , both parametric *t*-tests and the nonparametric Mann-Whitney U statistics were used. Compilations of qualitative data from the focus group interviews incorporated the multi-layer analysis described above that examined and coded each statement according to categories created through multiple readings of the responses.

Results

Implementation of the Model

This section focuses on the feasibility of the implementation of the model by the treatment teachers as evidenced by the degree to which the targeted nature of science concepts were incorporated into their instructional plans and lessons.

Unit plans developed by treatment teachers . In preparing unit plans, the eight treatment teachers followed a general format for the units that required them to specify both the biology topics and the nature of science issues which they intended to address in the lessons. Although teachers had conducted the historical research collaboratively in groups of four, their subsequent instructional unit plans were developed individually and no two units were identical. Table 4 shows the of the nature of science concepts addressed by each teacher and the degree of inclusion of each nature of the nature of science concepts in their plans. The degree of inclusion (*Little, Moderate, Great*) was determined from the teachersf stated objectives, lesson notes, questions for students, and assignments for students.

Table 4

Analysis of Unit Plans

	Units Addressing Evolution				Units Addressing Circulatory/Respiratory Systems			
	3Mike	1Eliz	3Sarah	2Mary	3Allison	1Ruth	3Ron	3Nora
Nature of Science Concepts								
Tentativeness of Scientific Knowledge	M		G		M	G	G	M
Importance of Replication of Studies	M	M					L	L
Nature/Role of Theories	M	G				L	L	
Public Nature of Science	G	G	G	G	M	M		G
Normal vs. Revolutionary Science								L

Note-- Names of participants were changed to protect their anonymity.

Degree of inclusion: L = little; M = moderate; G = great

1pre-service student teacher

2graduate student in science education who has had no student teaching experience

3experienced high school biology teacher

As Table 4 shows, the two issues most frequently addressed were the tentativeness of scientific knowledge and the public nature of science, both of which are ideas easily extracted from historical studies. In contrast, normal versus revolutionary science was mentioned only once, perhaps reflecting the fact that the issue is a philosophical consideration not so obvious in a relatively limited study of cases relating to a single biology topic.

Since the purpose of the study was to assess the effects of teachers incorporating nature of science concepts in a natural way into the biology content rather than to address them as separate topics, the researcher also examined the treatment teachers unit plans for logical connections between the two components. Table 5 summarizes the types of connections teachers made for three of the nature of science concepts noted in Table 2.

Table 5

Examples of Connections Between Nature of Science Concepts and Biology Content Made in Unit Plans

Nature of Science Concept	Connection to Biology Content
Tentativeness of Scientific Knowledge	Examined topics historically to illustrate the changing nature of accepted knowledge in the field.
Public Nature of Science	Explored biographical information on scientists to find the influences on their work by the published works of other scientists or by collaborations within the scientific community. Emphasized conflicts between scientists as factors important in the evolution of theories. Provided evidence of replication studies used to support or refute prevailing theories
Nature and Role of Theories	Contrasted theories with facts and hypotheses Noted influence of prevailing theories on scientists' thinking Traced refinement of theories through advances in knowledge and technology Compared rarity of new revolutionary theories with slow refinement and enlargement of existing theories

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Treatment and control teachers(estimates of teaching nature of science concepts. The last component of Nature of Science Questionnaire administered to both treatment and control teachers at the end of the school year in June asked them to indicate the specific nature of science concepts addressed in their instructional plans over the school year. Since they did not teach an entire school year, graduate students in each group (n=1) did not respond to this item. Table 6 shows the frequency of both appropriate and inappropriate references to nature of science concepts for the treatment (n=7) and control (n=7) teachers. As Table 6 shows, treatment teachers reported a greater frequency and range of appropriate references than controls and reported no inappropriate references. By way of contrast, the control teachers reported significant numbers of inappropriate references indicating substantial misconceptions of the nature of science concepts which are required as part of the State Standard Course of Study in all biology courses. Clearly, the findings are suggestive that treatment teachers had a greater understanding of the nature of science concepts and principles they were addressing instructionally, an interpretation consistent with more direct forms of data presented later in this section.

Table 6

Concepts Addressed in Instructional Plans for Year by Treatment and Control Teachers

Concepts Cited	Number of References made by Treatment Group Teachers	Number of References Made by Control Group Teachers
Nature of Science		
Tentativeness of Scientific Knowledge	6	2
Public Nature of Science	4	4
Role of Theories	1	1
Nature of Theories	3	0
Historical Nature of Science	3	0
Importance of Replicating Studies	1	0
Not Nature of Science		
Scientific Names	0	1
Equilibrium	0	1
Evolution	0	2
DNA	0	1
Genetics	0	1
Biotechnology	0	1
AIDS	0	1
Spread of Disease	0	1
Spontaneous Generation	0	1

Classroom implementation of instructional plans by treatment teachers. Analysis of logs kept by the teachers and the classroom observations made by the researcher addressed the question of the extent to which treatment teachers incorporated nature of science concepts in their biology teaching. Included in these records were both the formal units developed during training sessions as well the incorporation of nature of science concepts not directly addressed in the benchmark lessons developed in the workshop environment.

At the beginning of the 8-day program, all treatment teachers received a notebook to be used as a cumulative log, along with instructions to make brief journal-type entries, as appropriate. Although the teachers often elaborated in the logs beyond the specific date, biology content topic, and nature of science concept information required, the summary analysis of the logs presented in Table 7 focuses on the nature of science topics addressed with an indication of the biology context in which they were mentioned (if any).

Table 7

Nature of Science Topics Reported in Logs

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	Frequency of Reference to Nature of Science Concepts by Participants with Indications of Biology Context in which Reference was Made						
	Mike	Eliz.	Sarah	Allison	Ruth	Ron	Nora
Nature of Science Concepts							
Historical Nature of Science	1 *micro-biology*	1 *prob-ability*		1 *classifi-cation* 1 *viruses*	1 *micro-biology*		1 *genetics* 1 respira-tory systems
Tentativeness of Scientific Knowledge	1 .evolution	1 *ecology* 1 evolution	1 *sponta-neous generation* 1 evolution	1 evolution 1 *viruses*	1 *micro-biology*		1 *plants* 1 respira-tory systems
Scientific Methodologies		1 *populations* 1 no biology ref.	1 *populations*		1 *plants* 1 *micro-biology*		1 *plants*
Nature/Role of Theories		1 evolution 1 no biology ref.	1 evolution		1 *micro-biology*	1 *genetics*	1 respira-tory systems
Public Nature of Science	1 evolution		1 evolution		1 systems 1 *micro-biology*	1 *DNA*	1 respira-tory systems
Importance of Replication	1 evolution		1 no biology ref.		1 *ecology*		
Probabilities in Scientific Evidence			1 *DNA*				
Role of Scientific Community			1 evolution				
Philosophies of Science	1 evolution						
Pre-Conceptions of Scientists	1 evolution	1 no biology ref.	1 evolution		1 *ecology*		

Note-- Italicized words indicate topics for which plans were prepared outside the scope of the project training.

As Table 7 indicates, the treatment teachers generally included nature of science concepts into their regular biology instruction rather than teaching the concepts as isolated pieces of information. In only four entries out of 45 were nature of science concepts mentioned outside the context of biology content. Although the professional development sessions provided the opportunity to interweaving biology content and nature of science concepts in the form of a benchmark unit per group of four, the teachers obviously found ways to implement the technique individually in other units of study as well. More specifically, since only "Evolution" and "Systems" were the topics addressed in the benchmark units developed in formal training, the additional biology topics in Table 7 clearly indicate a substantial expansion of nature of science concepts into other instructional units in biology.

Complementing teacher logs, classroom observations also were conducted by the researcher twice during the school year. Table 8 summarizes the resulting classroom observations, including the concepts addressed, the frequency of each, and whether the reference was explicit or implicit. As Table 8 shows, the frequency of concepts most often addressed in the lessons, either explicitly or implicitly, were the public nature of science, the historical nature of science, and the tentativeness of scientific knowledge.

Table 8

Classroom Observations of Nature of Science Concepts by Treatment Teachers

Concept	1Frequency of Explicit References	2Frequency of Implicit References
Importance of making scientific findings public through publications and/or presentations	4	8
Idea that scientific knowledge shows historical development, though not cumulative	5	6
Role of theories in guiding work of a scientist	1	3
Idea that scientists are not necessarily objective when doing research	3	3
Tentativeness of scientific knowledge	4	8
Value of all scientific findings, even those that may be eventually replaced	2	1
Idea that most scientific work is focused on enlarging existing theories, not on new theories	3	4
Idea that consensus among scientific community is criterion for judging value of a theory	1	1
Importance of replication of studies by other scientists	2	2
Idea that theories do not have to be "proved" to be useful	1	3
Idea that theories are broad explanations made of related hypotheses that have gained substantial support	2	1

Note6

1Example of explicit reference: Use of a statement such as, "Since our ideas about the workings of the circulatory system in humans have changed through time with new studies, it is obvious that our knowledge in this area is tentative."

2Example of implicit reference: Presentation by the teacher or students of scientific studies through time in which changes in accepted views are obvious but no direct mention is made of the tentativeness of our knowledge in this field.

Impact of Training and Implementation of the Model on Biology Teachersſ Knowledge of the Nature of Science

Table 9 summarizes the mean differences between the treatment and control teachers on the Nature of Science Questionnaire scores in each of the 10 nature of science concepts shown in Table 2. As Table 9 shows, treatment teachers not only displayed a greater ability to choose statements consistent with a contemporary view of science (t (14)= 5.04, p< .05), but also demonstrated higher quality responses in the written rationales (t (14)= 5.66, p< .05) and the examples included in the rationales(t (14)= 7.30, p< .05) .

Table 9

Comparison of Mean Scores of Experimental and Control Groups on the 10-Item Nature of Science Questionnaire

		Mean scores on components across questions					
Group	n	aChoice of statement consistent with contemporary view of science		bQuality of rationale for choice		cQuality of example(s) as part of rationale	
		M	SD	M	SD	M	SD
Treatment	8	2.91	.13	2.61	.13	2.54	.21
Control	8	2.49	.20	1.98	.29	1.93	.11
t (14)		5.04*		5.66*		7.30*	

* p < .05

In comparing the findings for the three categories of responses, the smallest difference was found between scores a choice from among three options while the larger differences were in the areas in which teachers were required to compose a paragraph to support their selection. This finding is suggestive that participation in the project contributed substantively to teachers' understanding of underlying reasons for key tenets of the nature of science rather than their recognition of them.

Table 10 presents the results of individual Mann Whitney U statistical analyses comparing the responses of treatment and control teachers of each of the ten questions on the *Nature of Science Questionnaire* for "Consistency of Statement Chosen," "Average Quality of Rationale and Example," "Quality of Rationale,", and "Quality of Example." As Table 10 shows, although significant overall (see Table 9), treatment teachers

Table 10

Rank Sum Differences between Experimental and Control Teachers on Each of Nature of Science

Questionnaire Items

Group	Consistency of Statement Chosen	Average Quality of Rationale/Example	Quality of Rationale	Quality of Example
Question #1: Public Nature of Science				
Treatment	72.0	99.0	96.0	93.0
Control	64.0	37.0	40.0	43.0
U Statistic	28.0	1.0	4.0	7.0
X2, 1df	1.00	11.82*	11.20*	8.37*
Question #2: Tentativeness of Scientific Knowledge				
Treatment	68.0	88.5	88.5	82.0
Control	68.0	47.5	47.5	54.0
U statistic	32.0	11.5	11.5	18.0
X2,1df	0.00	4.91*	6.00*	2.45
Question #3: Historical Progression of Science				
Treatment	72.0	89.0	82.0	88.0
Control	64.0	47.0	54.0	48.0
U Statistic	28.0	11.0	18.0	12.0
X2,1 df	1.00	5.34*	2.63	5.56*
Question #4: Importance of Replication of Studies				
Treatment	76.0	89.0	81.0	93.0
Control	60.0	47.0	55.0	43.0
U Statistic	24.0	11.0	19.0	7.0
X2, 1 df	2.14	5.42*	2.18	7.81*
Question #5: Role of Theories				
Treatment	72.0	97.0	92.0	88.0
Control	64.0	39.0	44.0	48.0
U Statistic	28.0	3.0	8.0	12.0
X2, 1 df	1.00	10.17*	8.73*	6.82*
Question #6: Objectivity of Scientists				
Treatment	69.0	80.5	82.0	68.0
Control	67.0	55.5	54.0	68.0
U Statistic	31.0	19.5	18.0	32.0
X2, 1 df	0.019	1.92	2.36	0.00

Question #7: Theories vs. Laws				
Treatment	92.0	94.5	91.0	88.0
Control	44.0	41.5	45.0	48.0
U Statistic	8.0	5.5	9.0	12.0
X2, 1 df	9.00*	8.45*	7.07*	5.95*
Question #8: Construction of Theories				
Treatment	80.0	82.0	61.5	84.0
Control	56.0	54.0	74.5	52.0
U Statistic	20.0	18.0	25.5	16.0
X2, 1 df	2.14	2.25	0.49	5.00*
Question #9: Normal vs. Revolutionary Science				
Treatment	72.0	82.5	81.5	84.0
Control	64.0	53.5	54.5	52.0
U Statistic	28.0	17.5	18.5	16.0
X2, 1 df	1.00	2.68	2.68	3.56
Question #10: Role of the Scientific Community				
Treatment	80.0	88.5	84.5	84.0
Control	56.0	48.5	51.5	52.0
U Statistic	20.0	12.0	15.5	16.0
X2, 1 df	3.46	4.63*	3.27	3.87*

Note -- Larger rank sums for treatment teachers indicate higher levels of performance.

*$p < .05$

significantly outperformed control teachers on only 1 of the individual 10 questions (Question 7) on "Consistency of Statement Chosen," a recognition task. However, on "Average Quality of Rationale/Examples", which required construction (rather than recognition) of responses in support of the statement selected, treatment teachers outperformed controls on 7 of the 10 individual questions (Questions 1, 2, 3, 4, 5, 7, 10). Thus, the overall results in favor of the treatment teachers (see Table 9) were consistently supported by the "Average Quality of Rationale/Examples" findings for individual items. Finally, also shown in Table 10 are the findings for the individual "Quality of Rationale" and "Quality of Example" items. In inspecting Table 10, these findings should be interpreted as explanations of which of these measures contributed to the overall in-depth understanding of the nature of science items reflected by the "Average Quality of Rationale/Examples." As Table 10 shows, significant differences in favor of the treatment teachers were found on "Quality of Rationale" for Questions 1, 2, 5, and 7, while significant differences in favor of treatment teachers on "Quality of Example" were found for Questions 1, 3, 4, 5, 7, and 8.

In interpreting the individual item findings Table 10 within the context of the overall *Questionnaire* findings reported in Table 9, it should be noted that of the significant rank sum differences reported, all cases of significant differences found were in favor of the treatment teachers, as were all rank sum differences, whether significant or not. Thus, the treatment teachers clearly demonstrated greater overall knowledge and understanding of nature of science concepts than did comparable control teachers as measured by the *Nature of Science Questionnaire* . Analysis of individual questions also showed statistically significant differences in scores on at least one component in eight of the ten items. With regard to question #7, addressing the distinction between theories and laws, the treatment teachers scored higher on every component, a result which addresses the literature's attention to the common misconceptions among teachers related to theories and laws. The only questions which showed no statistically significant differences between groups on any of the three components taken individually were those focusing on scientists' primary involvement in normal rather than revolutionary science and the influence of theories on scientists' observations.

Perspectives of Treatment Teachers on the Project Model: Focus Group Findings

Treatment of the focus group interview transcript for treatment teachers involved iterative analysis and coding of each statement to include indications of the project's effect in each of the following categories: (1) increasing teacher understanding, (2) facilitating implementation efforts during the course of the project, and (3) providing assistance in planning for future implementation efforts. These three categories were pre-determined during construction of the interview questions and then critically evaluated after the transcript was prepared and examined to determine whether statements referred to an inadequate previous understanding or an improved new understanding or both. A third level of analysis identified the context of the statements, sorting them according to

Table 11

Indications of Understanding from Focus Group Interview

	Interview Statements Related to Teacher Understandings	
Concepts Mentioned in Reference to Understandings	1Number Indicating Improved Understandings	2Number Indicating Inadequacies of Previous Understanding
Nature of Science (General)	5	5
Nature/Role of Theories	4	6
Role of Observations	2	1
History/Philosophy of Science	5	2

Note --

1Example: " . . . we learned that most scientists don't even employ the formal steps of the scientific method in their method of discovery."

2Example: "I was real heavy into 'seeing is believing' . . . and that might not be the one best way to teach in the classroom."

their references to the following: (1) nature of science in general, (2) nature/role of theories, (3) scientific method,

(4) role of observations, and (5) history/philosophy of science. The teachers' general perceptions of changes in understandings are summarized in Table 11. Of special note is the number of statements indicating changes in understanding related to the nature and role of theories, confirming studies which indicate widespread misconceptions among teachers regarding theories.

From an analysis of the unit plans, the open-ended question, and the focus group interview, the evidence indicated that the treatment teachers readily incorporated nature of science topics into their instructional plans. The analysis of data from the questionnaires and from the focus group interview showed that the professional development sessions were effective in enabling teachers to develop a more valid and deeper understanding of the nature of science. In support of the statistical evidence, the verbal responses of the treatment teachers shown in Table 12 during the interview represented their perceptions that participation in the project and use of the model made a difference in their understanding of the nature of science.

Table 12

Incorporation of Concepts in Instructional Plans from Focus Group Interview

Participant	Comments
Ruth	*I don't know if I would have incorporated the stories about Robert Koch or Edward Jenner except for the seminars. That human aspect of science appealed to them.*
Nora	*I plan to use a lot of the information we talked about when we start our independent research projects. Sarah and I have talked and I think we are both going to begin our independent research projects earlier next year and let them get started on a lot of ideas or thinking about what a scientist has to do to solve a problem or even state a problem.*
Sarah	*I would like to do this kind of lesson the first marking period--to get them used to looking at different ideas different scientists had on a particular topic--and how they are related or how they are different.*
Mike	*I would not have had the time or been able to go get the resources needed to put this unit together if it weren't for this seminar and the resources it provided. Now I might be more willing in the future, I guess, because I know where to get started . . .*
Allison	*I think a lot of them think science is magic and they take so much for granted that all of our problems are going to be solved by somebody--just somebody out there. And I think this is good for them to think about how did we get to where we are--which is what this unit is going to address.*
Ron	*I incorporated the list of different views from the card exchange game into the unit I was planning for my AP kids. My idea is to have them write a brief essay explaining which statement best describes their view of science and why.*
Nora	*I like Ron's idea, but I plan to let that be my first lesson and then to do it again the last week of school and compare the before and after--let the students see how they might have changed.*
•Sarah	*I thought (the model lesson on cell theory) was really good. I plan to use it next year.*
Elizabeth	*Although I developed the unit on evolution, I think it was hard because the concepts are hard. I think the kids like the topics on systems because there is more blood and guts. I plan to use a historical approach with systems--because you can find a lot of historical data from books on history of medicine--not just respiratory and circulatory but other systems as well; . . ., it will be easier to develop other units now.*
Nora	*I plan to give the students more responsibility next time. I want to assign it one day and then two weeks later we will prepare group presentations. Then that gives the children time to go to the library and do their research.*
Ruth	*I think this seminar needs to be in the spring so we can begin in the fall because I think it's real important for the students to get this started at the beginning as a way to view science, and then we can incorporate the concepts all through the year.*
Mike	*I think next year and from now on I will be more aware of trying to be more explicit, trying to point out these ideas where it is appropriate.*
Nora	*I think by not saying today "this is what we're getting at" they probably have missed the point. We have assumed too much about what they are picking up. I see now that, at least at the beginning, I have to help them draw conclusions about the nature of science from the assignments. It is not obvious to them--just as it wasn't to us.*
Elizabeth	*I know I would never have done any of this. I've never had a class on it. I've never been taught it. I never would have known it. So I know I wouldn't have done it. But now that I've been exposed to it and am aware of it, I will use it in my instruction.*

Summary and Discussion

The findings of the study in relation to the original research questions can be summarized as follows:

1. The prototype model using historical cases was confirmed as feasible for use by secondary teachers in biology to address nature of science concepts.

2. The associated after-school staff development program supporting the implementation of the model was found effective in developing the knowledge and skills necessary for teachers to implement the model in secondary biology instruction.

3. Participation in the project and use of the historical cases model was found to enhance teachersf own understanding of key nature of science concepts. Consistent with the literature, findings of the study were suggestive that the very limited understanding of the nature of science concepts by control teachers was not adequate to teach the concepts and principles in depth and, very possibly, resulted in communication of serious misconceptions to their students.

From a proof-of-concept perspective, the prototype model using historical cases to embed nature of science concepts within science instruction was found to be both feasible and effective with the secondary biology teacher-participants.

Issues for Continuing Research and Development

Resource material development for teacher use . In interpreting the findings of the study, a major emphasis must be placed upon the importance of the resource materials relating to the nature of science and the history of biology that served as the substantive focus of the training program. Without such resource materials, teachers would have been unable to complete the curriculum planning required to implement the model effectively. In this regard, future work addressing the further development of the model has targeted the development, banking, and indexing for accessibility of historical cases for teachersf use via electronic means (e.g., via Internet database). Such materials could provide teachers with efficient access to the resources they need to implement the model in biology as well as in other science areas. However, at the same time, the question of whether teachers have the core preparation for the in-depth understanding of nature of science concepts necessary to teach them effectively without explicit professional training in some form is an open question to be answered by future research. In this regard, consistent with the professional developmental literature, the researchers anticipate that all of the components of staff development model used in the present study will prove necessary for optimal efficiency.

Development of instruments assessing student understanding of the nature of science . In a related issue, although future work in this area is planned by the researchers, the present study did not address the question of student achievement. Although this originally was planned in the original design of the study, subsequent inspection of the State Biology Test administered at the end of the school year revealed that Nature of Science understanding was tested only in a superficial manner by a relatively small number of items. Because the State tests are secure prior to administration, this methodological problem could not be anticipated. Thus, the available student performance data on the State tests consisted of a relatively few number of items of questionable curricular validity. As a tool for future research, the researchers are presently completing the development of a criterion-referenced test focusing on the 10 key nature of science concepts and principles shown in Table 2 using a format similar to that of the Nature of Science Questionnaire instrument used with teachers in this study.

Parametric studies exploring the effectiveness of the historical cases model . As part of a programmatic research effort expanding the application of the historical cases model to other secondary science areas, an important research concern has to with curricular variables associated with the use of the historical cases as a vehicle to teach nature of science concepts. These include (a) the frequency necessary for the different examples illustrating the nature of science concepts to result in student understanding, (b) effects of the distribution (over the scope and sequence curricular timeline) of the illustrative examples upon student retention and capability to apply the nature of science concepts, and (c) the effects of curricular characteristics of the science concepts in which the historical cases examples are embedded (e.g., is a variety science concepts more effective than a small number.) All of these research concerns are of practical importance in designing the scope and sequence component of the historical cases model.

Teachers and Students as Meaningful Learners: Implications for Future Development of the Model

In evaluating the present study, a great deal of current research in science education has focused on teaching for student understanding, encompassing topics such as constructivism, conceptual change and misconceptions (Matthews, 1997; Ogburn, 1997). Focusing on constructivism as the major plank in contemporary proposals for renewal in science education, Matthews (1994) acknowledged itsf enormous impact on the theory and practice of contemporary science education. The design of this study incorporated instructional practices inspired by constructivism (though not unique to it), such as active engagement of learners and attention to prior beliefs and knowledge. In an effort to confront platitudes about science that have been absorbed superficially by teachers from textbooks and the popular culture, the historical cases model used provided teachers with the means to gather their own evidence to support or refute their prior conceptions as well as the contemporary views of science presented in the literature. In turn, teachers seemed readily to be able to apply the historical evidence, even when it disputed views that they originally held. Perhaps because of the fact that they compiled the evidence themselves and it was not imposed upon them, they did not seem threatened when their initial views were challenged.

Since teachers are first learners, constructivism surely has implications for them as well as for students, particularly in an area such as the nature of science, identified as equally problematic for teacher and student understanding. Without probing the complex epistemological and ontological claims of some prominent constructivists, it is reasonable to propose that the instructional implications of constructivism be applied to teacher preservice and inservice education, particularly in areas where naive or incomplete conceptions are likely to exist. Thus is particularly appropriate for science teachers, because the identification of evidence as a basis of constructing knowledge is a fundamental aspect of science. If preservice and inservice teachers are given the tools by which they can conduct research to develop their own evidence, they might then be more amenable to conceptual change. In turn, modeling the instructional strategies that are effective with teachers could be an effective tool for affecting how teachers design instruction for their students. Although not investigated formally in the present study, the treatment teachers were observed (and reported) that their instructional practices with students were consistent with the strategies used by them in the professional development setting that resulted in their own understanding of nature of science concepts. Therefore, future developmental research with the historical cases model will, at some point, necessarily begin to incorporate a formal instructional strategies component into the historical cases model.

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Appendix

Specific Contrasting Statements for Each of the 10 Nature of Science Questionnaire Items

Question #1: Public Nature of Science

Opposing Statements	
Consistent:	Not consistent:
Most scientific work is a public matter, in which knowledge is shared openly, results are scrutinized carefully by others, and criticisms of scientific work are widely publicized.	Most scientific work is private, with scientists working in industrial or academic labs, keeping their results to themselves and their employees or funding sources, and feeling reluctant to criticize the work of other scientists.

Question #2: Tentativeness of Scientific Knowledge

Opposing Statements	
Consistent:	Not Consistent:
All scientific knowledge, even that which is universally accepted today, remains tentative and subject to future revision.	Scientific findings represent authoritative, indisputable knowledge once they are proved.

Question #3: Historical Progression of Science

Opposing Statements	
Consistent:	Not Consistent:
Ideas such as Lamarck's are part of a natural progression in the development of science, and some ideas currently accepted by the scientific community will probably be judged in the future to be as naive as Lamarck's.	Ideas like Lamarck's theory of evolution, now considered outlandish by some, represent a naiveté that existed only in the pre-modern era.

Question #4: Importance of Replication of Studies

Opposing Statements	
Consistent:	Not Consistent:
Research findings are generally viewed with skepticism until they are validated by replication.	Because replication of studies by the scientific community is often redundant, it is necessary only when the researcher's techniques are questionable or when they conflict with established findings.

Question #5: Role of Theories

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Opposing Statements	
Consistent: Scientific theories play a fundamental role in the work of most scientists.	Not Consistent: Since scientific theories have not been proved, their use in science is not valued as much by scientists as theory-free experimentation.

Question #6: Objectivity of Scientists

Opposing Statements	
Consistent: The observations made and recorded by most scientists are somewhat subjective in that they depend at least in part on the theories that scientists adopt.	Not Consistent: Most scientists depend on direct, objective observation more than on previous findings or pre-existing theories.

Question #7: Theories vs. Laws

Opposing Statements	
Consistent: No matter how much evidence is amassed in support of a theory, it will not become a scientific law.	Not Consistent: As theories are supported by more and more experimental evidence, they may eventually be proved and then become scientific laws.

Question #8: Construction of Theories

Opposing Statements	
Consistent: Just as an architect invents a structural design, a scientist may invent a theory.	Not Consistent: Just as an explorer discovers a new island, a scientist may discover a theory.

Question #9: Normal vs. Revolutionary Science

Opposing Statements	
Consistent: The focus of most scientists' work is to support, enlarge, or alter theories that already exist.	Not Consistent: The focus of most scientists' work is the development of new theories.

Question #10: Role of the Scientific Community

Opposing Statements	
Consistent: If there are two competing theories in a particular area, the better of the two is a matter of consensus among scientists arising from critical scrutiny.	Not Consistent: If there are two competing theories, the better of the two is the one which is nearer to the truth.

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