THE NATURE OF SCIENCE AND SCIENTIFIC KNOWLEDGE: IMPLICATIONS FOR DESIGNING A PRESERVICE ELEMENTARY METHODS COURSE

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ABSTRACT: This article describes teaching considerations related to the nature of science and scientific knowledge in an elementary science methods course. The decisions that were made, the rationale upon which these decisions were based, and the challenges evident are presented. Instructional strategies used during the course for the purpose of developing preservice teachers' understandings of the nature of science and scientific knowledge are described. The results of using these strategies, in regard to the impact on students' learning and their views on teaching the nature of science to elementary grade students are then discussed. The article concludes with a discussion on the implications for teaching the nature of science and scientific knowledge in the context of preservice elementary teacher education.

INTRODUCTION

This article presents a summary of challenges that are evident and decisions that have been made regarding efforts to both teach and research the teaching of the nature of science and scientific knowledge. The sources of information upon which the views expressed are based include the practical experiences of teaching the nature of science and scientific knowledge to middle school students and preservice elementary education teachers, an examination of literature over 30 years, the results of research studies conducted at various levels of education, data collected during the evaluation of efforts to reform science education, and current national standards for teaching the nature of science. The context for which the information presented has implications is the preparation of preservice elementary science teachers.

The experiences of this author when designing and teaching an elementary science methods course has led to the following questions regarding the nature of science and scientific knowledge:

1) What aspects need to be included to fully represent the multi-faceted nature of science?; 2) What are the most effective ways of developing these understandings?; and 3) What is a realistic expectation, in the context of this course, in regard to developing these understandings? The challenges evident in answering these questions include a literature base that defines the nature of science and scientific knowledge in a variety of ways and through the use of inconsistent terminology, a research base that is largely incomplete, and a general lack of attention to the nature of science and scientific knowledge by science education curricula at the K-12 and university levels. A careful examination of literature-based information which does exist, coupled with the knowledge base relating to constructivist teaching premises, however, has resulted in successful efforts to incorporate learnings about the nature of science and scientific knowledge in an elementary science methods course.

CONSIDERATIONS RELATED TO TEACHING THE NATURE OF SCIENCE AND SCIENTIFIC KNOWLEDGE

Meanings Associated With the Nature of Science and the Nature of Scientific Knowledge

The nature of science and nature of scientific knowledge are two dimensions of scientific literacy sometimes used interchangeably in the literature to refer to the same understandings. There are, however, distinctions between these two dimensions of scientific literacy which merit discussion. The differences generally relate to the distinctions which can be made between the terms "science" and "scientific knowledge". The definition of science presented below, used as a working definition of science in the author’s course, helps to depict the distinctions made between the nature of science and the nature of scientific knowledge. Aspects of this definition which depict the nature of science attest to science as a human activity, a process used to investigate natural phenomena, a process used to add to an existing knowledge base, and a social enterprise. Scientific knowledge, as presented in the definition, is a product of the human process of science and its social context.

> A Working Definition of Science: Science is a human activity through which problems and questions dealing with natural phenomena can be identified and defined, and solutions proposed and tested. In this process, data are collected and analyzed, and available knowledge is applied to explaining the results. Through this activity, investigators add to the store of knowledge, thereby helping people better understand their surroundings. Applications of this knowledge also may bring about changes in society and the cultural order and may have a direct bearing on the quality of life (Wisconsin Department of Public Instruction, 1986).

Definitions of the nature of scientific knowledge presented in the literature are diverse and multi-faceted. Showalter (1974) used the terms tentative, public, replicable, probabilistic, humanistic, historic, unique, holistic, and empirical to characterize the nature of scientific knowledge. After conducting a review of literature on the nature of scientific knowledge, Rubba and Anderson (1978) consolidated the nine factors identified by Showalter into a six-factor model called *A Model of the Nature of Scientific Knowledge.* The six factors included by Rubba and Anderson are defined as amoral (scientific knowledge itself cannot be judged as morally good or bad), creative (scientific knowledge is partially a product of human creativity), developmental (scientific knowledge is tentative), parsimonious (scientific knowledge attempts to achieve simplicity of explanation as opposed to complexity), testable (scientific knowledge is capable of empirical test), and unified (the specialized sciences contribute to an interrelated network of laws, theories, and concepts).

Cotham and Smith (1981) use the terms "tentative" and "revisionary" to define the nature of scientific theories. The tentative component of this conception emphasizes the inconclusiveness of all knowledge claims in science. The revisionary component emphasizes the revision of existing scientific knowledge in response to changing theoretical contexts.

While the nature of science has been used as terminology in the literature to represent the same facets as scientific knowledge, it is usually presented in a broader context. This broader context includes not only the nature of scientific knowledge, but the nature of the scientific enterprise and the nature of scientists as well (Cooley & Klopfer, 1963; Kimball, 1968).

A theoretical model of the nature of science was developed by Kimball (1968) out of extensive study of the literature on the nature and philosophy of science. The declarations forming this model are: (1) curiosity is the fundamental driving force in science; (2) science is a dynamic, ongoing activity; (3) science aims at comprehensiveness and simplification; (4) there are many methods of science; (5) the methods of science are characterized by attributes which are more in the realm of values than techniques; (6) a basic characteristic of science is a faith in the susceptibility of they physical universe to human ordering and understanding; (7) science has a unique attribute of openness; and (8) tentativeness and uncertainty mark all of science. This model is consistent in its agreement with views expressed by Conant (1961) and Bronowski (1953), and additional support for each assertion is found among the writings of other philosophers of science.

According to Klopfer (1969), the processes of scientific inquiry and the developmental nature of knowledge acquisition in science depict the nature of science. He identifies the understanding of how scientific ideas are developed as one of three important components of scientific literacy. According to Klopfer, every student must learn how scientific ideas are formulated, tested, and inevitably, revised, and he/she must learn what impels scientists to engage in this activity.

According to the objectives formulated by the National Assessment of Educational Progress (NAEP), the major purpose of science education is to develop scientifically literate individuals. The NAEP objectives for 1985-86, taking into account recent developments and new emphases, provide a definition of scientific literacy that includes both the body of knowledge in the traditional disciplines and knowledge about the nature and history of science. The Nature of Science category is designed to measure students' understanding of the characteristics and methods of scientific inquiry and their ability to apply the processes of science to the solution of problems. The History of Science is a new area of the assessment designed to measure students' knowledge and understanding about how scientific ideas and theories develop and change over time, how society has influenced scientific development, and how developments in science have affected society.

In a process that took three years, the National Council on Science and Technology Education, drawing on the expertise of scientists, engineers, mathematicians, historians, and educators, prepared a set of recommendations on what understandings and habits of mind are essential for all citizens in a scientifically literate society. These recommendations are presented in *Project 2061: Science For All Americans*, a report prepared by the American Association for the Advancement of Science (1989). An understanding of the nature of science is one of four categories of knowledge, skills, and attitudes identified by the national council as essential for all citizens in a scientifically literate society. Three principle components of the nature of science, as defined by the national council are (pp. 25-31):

> 1. Scientific world view - the world is understandable, scientific ideas are subject to change, scientific knowledge is durable, and science cannot provide complete answers to all questions;
> 2. Scientific methods of inquiry - science demands evidence, science is a blend of logic and imagination, science explains and predicts, scientists try to identify and avoid bias, and science is not authoritarian; and
> 3. Nature of the scientific enterprise - science is a complex social activity, science is organized into content disciplines and is conducted in various institutions, there are

generally accepted ethical principles in the conduct of science, and scientists participate in public affairs both as specialists and as citizens.

In summary, definitions for both the nature of scientific knowledge and science presented in the literature are multi-faceted. This multi-dimensional nature is due largely to the variety of disciplines from which the definitions were derived and a lack of agreement which has occurred within and across the disciplines of history, philosophy, and the academic sciences for what characteristics typify the complex and ever-changing field of science.

Relationship of the Nature of Science and Scientific Knowledge to Scientific Literacy

A decision by this author to study the nature of science and scientific knowledge in an elementary science methods course through the broader context of scientific literacy is based on a major objective of current science education reform to develop the scientific literacy of all students. Although there is no standardized definition of scientific literacy, the nature of science is consistently identified throughout the literature as a component of scientific literacy. An understanding of the nature of science in general, and scientific knowledge in particular, have been identified by scientists, leaders in the field of science education, and those involved in policy making arenas as a requisite learning goal for the attainment of scientific literacy over the course of the past three decades (AAAS, 1989; AAAS, 1993; Collette & Chiapetta, 1989; NRC, 1996; Pella, et al, 1966; Rubba & Anderson, 1978; Showalter, 1974).

Possessing accurate views about the nature of science and scientific knowledge is believed to contribute to a person's scientific literacy in a number of ways. According to Klopfer (1969) and

Duschl (1990), the scientifically literate person will be able to accept reformulations of scientific ideas, remaining unperturbed, only if he or she understands the developmental nature of scientific inquiry. Duschl (1990) warns that, without an adequate understanding of the warrants or reasons scientists use to change methods, beliefs, and processes, it is probable to expect that people will not acknowledge scientists' views as rational and as the end product of a process in which changes are both natural and expected.

Cotham and Smith (1981) identify an understanding of the tentative and revisionary nature of science as an important goal of education because of its implications for the public's understanding and support of the scientific enterprise. They agree that an understanding of the tentative and revisionary nature of science may serve as an antidote to cynicism about science. This cynicism often results when citizens who hold the view that science is a collection of immutable facts are presented with the changing knowledge claims of such rapidly developing disciplines as astrophysics, nuclear physics, and biochemistry.

Science Curricula: Inadequate Attention to the Nature of Science and Scientific Knowledge

Rather than helping students to develop meaningful understandings about scientific knowledge and the conditions by which it develops, science text materials contribute to the development of student views that scientific knowledge is an array of unconnected facts and concepts. According to Arons (1983), instructional efforts to cultivate scientific literacy flounder, first because they subject students to an incomprehensible stream of technical jargon that is not rooted in any experience accessible to the student, and second because the material is presented much too rapidly and in far too great a volume for any significant understanding of ideas, concepts, or theories to be assimilated. Arons warns that the pace makes difficult, if not impossible, for the development of any sense of how concepts and theories originate, how they come to be validated and accepted, and how they connect with experience and reveal relations among seemingly disparate phenomena.

Both pace and the volume of the material preclude any meaningful reflection on the scope and limitations of scientific knowledge or of its impact on our intellectual heritage and view of a human's place in the universe. In these circumstances, contends Arons, there is essentially no hope of developing insights and understanding that characterize genuine scientific literacy.

In addition to presenting a view that scientific knowledge is absolute truth, not subject to change, Duschl (1990), asserts that the nature of scientific inquiry is misrepresented in another way. Although an understanding of science inquiry includes not only processes for testing knowledge, but also processes for generating knowledge, Duschl (1990) and Kilborne (1980) report that the majority of elementary and secondary science textbooks have focused almost exclusively on processes associated within the context of testing theories. Knowledge claims in science are thus learned on the basis of their contribution to the established form of modern knowledge, while the processes which generated this knowledge are largely ignored.

Rubba, Horner, and Smith (1981) pose textbook expositions and science teacher behaviors that are at odds with the nature of science as the two most obvious sources for student misconceptions about the nature of science. They argue that secondary-science textbooks and even the "newer" curricula, with few exceptions, do not deal with the relationship among scientific explanations and contain statements that portray science as consisting of unalterable, fixed truths.

The purpose of an empirical study conducted by Lederman and Ziedler (1989) was to determine whether or not the language used and the manner in which it was expressed by teachers helped to develop student understandings of the nature of science. The NSKS was administered to teachers and their students at the beginning and end of one semester. Composite scores of student change for the NSKS subscales that best distinguished between the two perceptions of “science as absolute truth” and “science as explanations for ordering perceptions” were used. The results of this study reveal that the variables established statistically differentiated between these two perceptions of the nature of science with respect to teachers' language and subsequent changes in students' orientation. Lederman and Ziedler concluded that the ordinary language teachers use to communicate science content does provide the context in which students formulate their own conceptions of the nature of science.

An investigation of instruction addressing the components of scientific literacy and its relation to student outcomes was conducted by Mitman, Mergendoller, Marchman, and Packer (1987). The linkages between science content and its societal, reasoning, historical, and attitudinal implications were hypothesized by the investigators as contexts to facilitate scientific literacy. Classroom observational data revealed that the 11 seventh-grade life science teachers in the study rarely or never addressed the contexts of science identified by the researchers in their presentations and academic work assignments. Student perception data indicated that students viewed the explaining of factual content as the predominant focus of teachers' instruction.

Possible explanations offered by the investigators for the neglect of science contexts by teachers are that textbooks and other commercial sources made little or sporadic use of these contexts, that teachers themselves either did not subscribe to a framework of scientific literacy or were unable to allocate time to its development and articulation, and that teachers were never trained in how to enrich their curriculum in this fashion.

The results of Meichtry's (1992) study indicated that although the field-test version of the BSCS middle school science program exemplified the type of curricula supported by reform advocates, the understanding of students in regard to the developmental and testable nature of science actually decreased during the 26-week time period of the study. An analysis of curricular materials and classroom observation and interview data, used to help explain the results of Meichtry's study, provided evidence that the nature of scientific knowledge was not always being directly conveyed to students through either the written curriculum of BSCS or by the teachers. For example, even though students designed several experiments that required them to use creativity, neither the written text or teacher would directly inform students that this was a process used by scientists to generate scientific knowledge. Meichtry concluded that, when the curriculum or teacher did not directly relate the content students were learning or processes they were using to the separate dimensions of the nature of science defined in this study, it is reasonable to expect that the students did not make these connections themselves. One implication made evident by the results of Meichtry's study is that the mere use of a program designed to develop student understanding of the nature of science is no guarantee that such understandings will develop.

TEACHING THE NATURE OF SCIENCE AND SCIENTIFIC KNOWLEDGE IN A PRESERVICE ELEMENTARY SCIENCE METHODS COURSE

The course described in this article is a one-semester, 3 credit hour course. Students enrolled in the course are college seniors and graduate students seeking teacher certification. The vast majority of students take the course the semester prior to student teaching.

To overcome challenges presented by the lack of a standardized definition of the nature of science, the nature of science is characterized within the course by the two broad areas of the nature of scientific inquiry and the nature of scientific knowledge that results from such inquiry. Scientific inquiry is described as the processes used to generate and test scientific knowledge. These processes, more specifically, are presented as stating a research question, hypothesizing, observation, collection-recording-interpretation of data, and drawing conclusions. The two aspects of the nature of scientific knowledge emphasized within the course are the developmental and testable nature.

These “working” definitions of the nature of science and scientific knowledge prove useful with this population of students not only because their understanding of these aspects of the nature of science is very limited, but because these definitions are applicable to the teaching of elementary grade students. Science education standards, based on the most up-to-date learning theories, recommend an emphasis on teaching science process in the elementary grades (NRC, 1996).

As part of an action research effort to assess the effectiveness of teaching strategies to develop understandings about the nature of science and scientific knowledge, students were asked to define science on the first day of class. The results of this exercise revealed that students' viewed science primarily as a knowledge base to be studied and learned; their views of the processes of science were largely incomplete. These views of students are not surprising when considering the evidence presented in the literature that this aspect of science is the one most often neglected by school curricula and least understood by K-12 and university students alike.

As was done with defining the nature of science and scientific knowledge, scientific literacy is discussed in general terms which characterized the array of definitions presented in the literature and by current reform recommendations. The areas of scientific literacy studied in this course are an understanding of basic scientific concepts, the ability to use and understand scientific processes, the use of higher order thinking skills, and the development of scientific attitudes and value, such as objectivity, openness, the value of trial and error, intellectual honesty, and tolerance for ambiguity.

Overview of Teaching Methods

Various teaching approaches and activities are integrated within the course to help students develop more adequate views about the nature of science and scientific knowledge. In addition to strategies designed to develop these understandings, an attempt is made to help these students relate what they learned in their methods class about the nature of science and scientific knowledge to the teaching of elementary science. Teaching approaches used for these purposes include the following: 1) learning cycle lessons taught to peers and to elementary students (including a reflective analysis about what was learned about science and science teaching), 2) the design and implementation of a research experiment, a written research report, and sharing of results with peers, 3) a follow-up reflective analysis of the experiment, summarizing what was learned about the nature of scientific inquiry and knowledge and how such an experiment might be structured in an elementary classroom, and 4) a quiz on the nature of science and scientific knowledge.

Deepened understandings about the nature of science and scientific knowledge, developed as a result of teaching and being engaged in learning cycle lessons, include the importance of objectivity and open-mindedness involved in drawing conclusions and the importance of collecting valid scientific evidence through a trial and error process. The tentativeness and testable nature of knowledge produced throughout the lessons are understandings of the nature of scientific knowledge developed. These understandings were measured through the open-ended responses of students to the question, “Explain any change(s) in attitudes or beliefs about science that took place as a result of teaching or engaging as a student in a learning cycle lesson”. The results of the quiz, used as a measure to assess student understanding of the tentative and developmental nature of scientific knowledge, as well as the inquiry processes used to gather conclusive evidence, demonstrate that students have developed these understandings.

Student Research Experiment and Learning Results

While the learning cycle lessons and quiz, in addition to the modeling of scientific inquiry processes throughout the semester, help to develop student understanding, the primary course activity designed to develop student understanding of the nature of science and scientific knowledge involved them in an experience which required using the processes of science in the design and conduct of their own research study. Students, working alone or in groups of 2-4, are in complete control of this experience, from the development of a research question which interests them to the formulation of a hypothesis, the design of an experiment, the collection and recording of data, the interpretation of results, and the drawing of conclusions based on their results. Students are required to submit a written report of their work and share their results with the "scientific community" of their peers.

After conducting the research experiment and participating in the sharing of results through classroom presentations, students were asked to respond in writing to the following questions: 1) What did you learn about the nature of scientific inquiry and knowledge as a result of conducting the experiment and participating in the class presentations? and 2) What are your ideas about structuring experimentation experiences with elementary students? Student responses were categorized by the researcher into topics relating to the various aspects of the nature of science and scientific knowledge represented in the responses. Results of this action research revealed that the experience of actually using the processes of science to research a question had developed a greater understanding of the nature of science of virtually every student. Examples of student responses, when asked what they learned about the nature of science and scientific knowledge, are presented in Figure 1.

Figure 1. Research Experiment: Student Learning About Science Inquiry and Knowledge

The inquiry process generates more questions.

Having an open-mind about experimental results is important.

The inquiry process is a never-ending search for knowledge.

The usefulness of the steps of the scientific method is evident.

The meaning of trail and error in science is more clear.

Conclusions are often inconclusive and lead to other questions, hypotheses, and experiments.

Results can change each time you do an experiment.

When an experiment has been done many times, you should still say that the results "indicate" that....

Repeating experiments is important to get valid results.

Hypotheses are never wrong, they're just not supported by results.

Experiments don't fail - you learn from results.

The results of an experiment don't "prove" anything.

Inquiry involves creative thinking.

Science experiments can and should be simple.

The simplest of experiments can yield much information.

An area of positive change that occurs as a result of students conducting the research experiment, not reflected by Figure 1, concerns an internal shift in student belief systems that is very important to understanding the nature of science. Many of the students describe a shift in feelings from initially being very disappointed by having to reject their hypothesis to feelings of "it’s really ok if the hypothesis is rejected”. This new feeling emerges as a result of what students learn from the experiment and the realization that conclusions are based on the results of that one experiment.

Another interesting result is that many students volunteer the information that the experience of conducting a research experiment was their first ever. The most common, and often singular prior experience students have is doing a science fair project.

Research Experiments With Elementary Students: Learning Results

Although many responses to the question, “What are your ideas about structuring experimentation experiences with elementary students”?, relate to areas of learning not directly related to the nature of science and scientific knowledge, such as structure of student groups and time issues, there are numerous and varied responses related to the nature of science. First, virtually every student notes the importance of <u>doing</u> science research with elementary students. This in itself, is viewed as a significant result of students conducting their own experiment in a methods course.

The most frequent response given is the importance of teaching children that they have not failed if their experimental results are not what they expected. Another frequent response is the importance of children being involved in the "creation" of the experiment from beginning to end. Several students mention the importance of having students develop their own questions to investigate. Other responses include the importance of teaching the processes of science, the relevance of experimentation to real life, development of <u>clear</u> research questions, hypothesizing, observation skills, the concept of controls and variables, methods of reliable data collection, and basing conclusions on experimental evidence.

The developmental, testable, and creative nature of scientific knowledge are represented in student responses to how science research should be conducted with elementary students. The most significant growth in understanding, as reported by students, relates to the developmental nature of scientific knowledge.

ASSESSMENT OF SEMESTER LEARNING

In addition to the evaluative assessment of student learning which occurred as a result of separate activities completed during the course, research methodology was employed to assess learnings which occurred as a result of the course as a whole. Both qualitative and quantitative measures were used as pre-semester and post-semester comparative analyses. The results of each of these assessment indicate that student learnings about the nature of science and scientific knowledge, as a result of the course as a whole, were significant.

On the first and last day of class, students are asked to respond to the following questions: 1) What is science? and 2) How do you think science should be taught at the elementary level? The responses of students are categorized by the author into topics related to science as a content area and science as a process. Post-class responses to these questions reveal that students develop a much more complete understanding of the nature of science inquiry throughout the semester. Students heavily emphasize science as a body of knowledge on the first day of class in their understanding of what science is and how it should be taught to elementary students. Their views about the processes of science are largely incomplete. The number of student responses which depict science as a process, however, double from pre- to post-semster. Examples of processoriented responses include a way of thinking about problems and curiosities, a method of discovery, an organized process in which ideas are tested, conducting an experiment to test a hypothesis, science is ever-changing and growing with new information, systematic approach to obtain knowledge, involves repeated trials, science is an ever-changing experience, discovery-inquiry-exploration, and going through a process that involves thinking and may involve attitudes and values.

The number of responses which relate directly to teaching elementary school students the nature of science and scientific knowledge more than double from pre- to post-response. Examples of responses which relate to this area of science include the following: teach basic methods of discovery, teach and apply scientific method, hands-on learning for the purpose of teaching process, as a process to gain knowledge, finding answers to self-questions, design own means of solving problems, and allow students to test theories.

The Modified Nature of Scientific Knowledge Scale (MNSKS), developed by Meichtry (1992) as a modification of the Nature of Scientific Knowledge Scale (Rubba and Anderson, 1978), is used to measure and compare student views about four dimensions of the nature of scientific knowledge at the beginning and end of the semester. The four dimensions of scientific knowledge measured are the developmental, testable, creative, and unified nature of science. The MNSKS is administered as a pre test on the first day of class and as a post test on the last day of class. To determine whether the post-test mean scores of each of the four subscales of the MNSKS and the overall instrument differ significantly from pre-test mean scores, a paired comparison t-test analysis is conducted. To determine statistical significance at the .05 level, t statistics are calculated.

Table 1. Paired-Comparison T-Test for the MNSKS Pre- and Post-Test

N=67

Variable	Mean Difference	STD Error	T
PROB			
Developmental	1.31	0.38	0.0009
Testable	2.03	0.53	0.0003
Creative	2.30	0.56	0.0001
Unified	1.39	0.39	0.0007
MNSKS	6.49	1.19	0.0001

The results of the paired comparison t-test analysis, presented in Table 1 above , indicate that the increase in student understanding of the nature of scientific knowledge during the semester is statistically significant. These results, based on three classes of students during the same semester in 1995, are typical of courses taught during other semesters.

SUMMARY

The goal of developing students' own understandings of the nature of science and scientific knowledge while teaching them methods of developing their future elementary students' understandings is one of many goals of teaching a preservice elementary education science methods course. This goal can be accomplished by science teacher educators through the use of knowledge presented in the literature and the use of effective teaching practices.

The general views of the nature of science and scientific knowledge presented in the literature- the view of science as a process to generate and test knowledge, and the developmental and testable nature of scientific knowledge- are views relevant to the population of preservice elementary teachers. Effective teaching practices to use include the modeling of scientific inquiry processes and attitudes, providing “real” science experiences which enable students to construct their own knowledge of the nature of science and scientific knowledge, and requiring students to reflect on their new knowledge and the relationship of this new knowledge to the teaching of elementary grade students.

While there are science teacher educators who choose to include instruction related to the nature of science and scientific knowledge in a methods course, however, there are many faculty who do not. Moreover, the lack of consistency in which views about the nature of science and scientific knowledge are presented in the literature and the inadequate representation of both in K-16 science curricula merit the need for further research of and dialogue about the nature of science and scientific knowledge. Those involved in such research and dialogue should include not only science teacher educators, but K-12 science teachers, university science professors, science curriculum publishers at all levels, and scientists as well. More information and more explicit, convincing, and widespread communication about the importance of teaching the nature of science and scientific knowledge and how to do so is critical to the preparation of all science teachers.

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