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Examining Preservice Science Teacher Understanding of Nature of Science: Discriminating Variables on the Aspects of Nature of Science

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Examining Preservice Science Teacher Understanding of Nature of Science:

Discriminating Variables on the Aspects of Nature of Science

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy
in the Graduate School of The Ohio State University

By

William I. Jones

Graduate Program in Education

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Dissertation Committee:

Arthur L. White, Advisor

Donna F. Berlin

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Abstract

This study examined the understanding of nature of science among participants in their final year of a 4-year undergraduate teacher education program at a Midwest liberal arts university. The Logic Model Process was used as an integrative framework to focus the collection, organization, analysis, and interpretation of the data for the purpose of (1) describing participant understanding of NOS and (2) to identify participant characteristics and teacher education program features related to those understandings. The Views of Nature of Science Questionnaire form C (VNOS-C) was used to survey participant understanding of 7 target aspects of Nature of Science (NOS). A rubric was developed from a review of the literature to categorize and score participant understanding of the target aspects of NOS. Participants' high school and college transcripts, planning guides for their respective teacher education program majors, and science content and science teaching methods course syllabi were examined to identify and categorize participant characteristics and teacher education program features. The R software (R Project for Statistical Computing, 2010) was used to conduct an exploratory analysis to determine correlations of the antecedent and transaction predictor variables with participants' scores on the 7 target aspects of NOS. Fourteen participant characteristics and teacher education program features were moderately and significantly ($p < .01$) correlated with participant scores on the target aspects of NOS. The 6 antecedent predictor variables were entered into multiple regression analyses to determine the best-fit model of antecedent predictor variables for each target NOS aspect. The transaction predictor variables were entered into separate multiple regression analyses to determine the best-fit model of transaction predictor variables for each target NOS aspect. Variables from the best-fit antecedent and best-fit transaction models for each target aspect of NOS were then combined. A regression analysis for each of the combined models was conducted to determine the relative effect of these variables on the target aspects of NOS. Findings from the multiple regression analyses revealed that each of the fourteen predictor variables was present in the best-fit model for at least 1 of the 7 target aspects of NOS. However, not all of the predictor variables were statistically significant ($p < .007$) in the models and their effect (β) varied. Participants in the teacher education program who had higher ACT Math scores, completed more high school science credits, and were enrolled either in the Middle Childhood with a science concentration program major or in the Adolescent/Young Adult Science Education program major were more likely to have an informed understanding on each of the 7 target aspects of NOS. Analyses of the planning guides and the course syllabi in each teacher education program major revealed differences between the program majors that may account for the results.

Dedication

To my beloved father, Donald Jones

and

in loving memory of my mother, Mary Elizabeth Jones

Acknowledgments

A special thanks to my academic advisor and committee member Dr. Arthur White for his guidance, insight, and encouragement. Completing this project has been a long and arduous process, marked by many interruptions and changes. I am indebted to Dr. White for his willingness to step in as my advisor after the departure of two previous advisors from the university and for his patience when other professional demands were placed upon my schedule. His expertise, kindness, and patience have left an indelible impression upon me.

The impetus and initial framework for this project began with my participation in a seminar course led by Dr. Donna Berlin. Under her guidance and using her feedback I developed my research topic and began this journey. Dr. Berlin spent many hours reading first drafts of the project components and provided invaluable editorial comments and suggestions. Her contributions continued as a member of my committee and for this I am most grateful. The third member of my committee, Dr. Kathy Cabe Trundle, provided infusions of encouragement, accountability, and expertise at several key moments to move this project forward.   I am thankful for the time and effort she has invested in guiding my research efforts.

I relied on the expertise and know-how of my colleague Bob Schumacher to navigate the waters of statistics programs. Our many discussions afforded me the

opportunity to realize the full potential of statistics for use with my research interests. The consulting provided by Bob was essential to the completion of this project.

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Vita

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Major Field: Education

Specialization: Science Education

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Chapter 1: Introduction

Science has enhanced and enriched our lives and has the potential to continue to do so if people are knowledgeable of basic scientific principles and concepts and how science works. Such common knowledge of science is referred to as "science literacy" by two key publications influencing science teacher education: *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1990) and the *National Science Education Standards* (National Research Council [NRC], 1996). Both documents describe science literacy as the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, economic productivity, and securing national interests. A cardinal point to science literacy, as both documents assert, is the importance of students' understanding of the nature of science (NOS). Science is a human endeavor and it is a way of knowing that differs from other modes of knowing and knowledge types, e.g., religious and cultural. To understand how science differs from such other ways of knowing and its role in our society, students must know the rules of how science works, what is referred to as the nature of science (Clough, 2000: McComas, Clough & Almazoroa, 1998). Such rules stipulate what constitutes scientific knowledge and how such knowledge is to be developed, i.e., scientific inquiry. Specific attitudes, beliefs, and perspectives distinguish a scientific worldview from others and are a necessary part of what is called the “scientific enterprise.” Distinguishing aspects of the scientific enterprise set proper limitations on science and its processes (AAAS; NRC).

The emphasis placed on nature of science in the K-12 curriculum by the two science education reform documents influenced the science standards adopted by many states and their respective departments of education and both documents specifically address aspects of NOS throughout the K-12 science curriculum (AAAS, 1990; NRC, 1996). In states such as Ohio, aspects of NOS are represented as standards, benchmarks, and grade-level indicators (Ohio Department of Education, 2003). Thus, students in K-12 programs in many states, including Ohio, are compelled to learn not only science content in the traditional science disciplines but also aspects of NOS. To further emphasis the importance of NOS in the curriculum, teacher education programs in the state are accredited by the National Council for Accreditation of Teacher Education (NCATE). This accrediting agency uses standards established by specialty program areas which require teachers who instruct students in elementary, middle school science, and high school science classrooms to know, communicate, and assess their students’ understanding of aspects of NOS (National Association for the Education of Young Children, 2001; NCATE, n.d.; National Middle School Association, 2001; National Science Teachers Association, 2003).

However, a number of studies suggest that many students exiting K-12 programs as well as those in undergraduate programs have a number of alternative or uninformed conceptions regarding NOS (Lederman, 1999; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001; McComas, 1998). Student understanding of concepts and process skills which are included in the construct of science literacy may be influenced by their views of what science is and how it works. If students have an inadequate or uninformed understanding of NOS, such understanding may impede their understanding of other science concepts and conceptions. A number of uninformed views held by students have been identified and include (a) laws and facts represent certainty while theories are believed to be tentative, (b) laws are considered to represent a higher level of knowledge than theories, (c) scientific knowledge is certain and possesses absoluteness, (d) experiments are the principle means to scientific knowledge, and (e) science is procedural and lacks creativity (McComas, 1996, 1998). Student understandings of science and their subsequent application in personal and social decision making are hampered by such views (Nussbaum & Novick, 1982).

The *National Science Education Standards* (NRC, 1996) and the publication *Before It's Too Late* (U.S. Department of Education, 2000) suggest that the most direct way to improve science education is by means of high quality teaching. Such publications point to better teacher preparation and quality as central pillars to science education reform, including developing students' informed understanding of NOS. Thus inservice and preservice elementary teachers and science teachers must be well grounded in content knowledge—including NOS, fully licensed, and capable of raising the achievement levels of their students. The importance of NOS in teacher education programs arises in part from the common assumption that to teach content including NOS, teachers must have an adequate understanding of the content (Abd-El-Khalick & Lederman, 2000a; Lederman 1992a). A second assumption common to the science education community is that teacher views of NOS will translate directly to their classroom practice (Abd-El-Khalick & Lederman, 2000a; Lederman, 1992a). However, current research indicates an understanding of NOS is often lacking in science teachers and instructional practices of teachers are not commensurate with their views of NOS (Abd-El-Khalick & Akerson, 2004; Lederman,1999; Lederman et al., 2001). Preservice teachers, whether in elementary licensure programs or science education programs, are categorized by the same studies as having less than informed views of NOS.

Purpose of the Study

The purpose of this study is to examine the understanding of nature of science for participants enrolled in the teacher education program at a Midwest liberal arts university. Further, it seeks to identify factors or variables in the teacher education program and their relationship to participants' understanding aspects of nature of science (NOS). The research questions addressed in the investigation are:

1. What understanding do the participants of the teacher education program at a Midwestern liberal arts university near the completion of their licensure programs have of aspects of nature of science?
2. Would teacher education participants' understanding aspects of nature of science align with an informed, an uninformed, or a syncretic understanding of nature of science?
3. What variables or factors discriminate between the different levels of understanding aspects of NOS among the teacher education participants?

Significance of the Study

Studies have been conducted to examine and evaluate inservice and preservice elementary teacher, and science teacher understandings of NOS and related factors (Abd-El-Khalick, 2001; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000a, 2000b; Lederman, 1992a, 1999; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman et al., 2001). These studies limited their investigations to a particular population either within a teacher education program or by grade level, e.g., high school preservice teachers, elementary teachers, etc. What is needed is an examination of the understanding of NOS among a wider range of preservice teachers within the same teacher education program. Comparing this understanding across different teacher education program features may identify which features in the program promote the development of an informed understanding of NOS. Studies limited to one particular licensure group or grade-band may miss such features. Methods used in such an examination may serve as a template for evaluating teaching education programs in regards to participants' understanding of NOS.

A determination is also needed of the relationship of high school experiences that preservice teachers bring into a teacher education program to their understanding of NOS. The number of high school science courses, the types of high school science courses, ACT scores, the type of high school attended, etc. may be in some way related to and influence preservice teacher understanding of NOS. Identifying these characteristics may guide teacher education programs in determining admission standards, identifying at-risk participants for understanding NOS, and increasing the teaching effectiveness of their graduates.

Constructivism as an Interpretive Framework

Constructivism, as a theory of epistemology, provides an interpretive framework for understanding how people in general learn science and consequently has provided a framework for the development of several learning theories pertinent to science education. Such an interpretive framework is useful in understanding possible explanations for why students have alternative conceptions of science, specifically NOS, and the resistance of such alternative conceptions to alignment with informed views. The foundational principles of a constructivist epistemology are several. First, the pursuit of knowledge is an organization of the experiential world by the learner and requires her or his active participation and is not necessarily received passively (Staver, 1998; Wheatley, 1991). Thus, knowledge is actively built up from within by individuals and by individuals participating in a community. Learning in the community involves the learner being initiated into the practices and beliefs of the community (Rogoff, 1990; Vygotsky, 1986). Second, the way learners are introduced to such a community and a specific domain of knowledge is through discourse with others in the context of relevant tasks (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Knowledge is viewed as a process where interactions and the use of language between learners in a community results in a construction of specific knowledge corresponding to the tasks and sharing of ideas done by learners in cooperative learning groups (Wheatley). Social interactions between and among individuals in community settings are central to the building of knowledge by communities.

Another aspect of how people or learners construct such knowledge is addressed by Piaget's schema theory. Piaget posited that learners respond to their sensory experiences by building cognitive structures or schema in their mind (Saunders, 1992). These schemas constitute the meaning and understanding of their world, in essence creating meaning in the mind of the learner. Such structures allow the learner to make predictions and develop explanations for those predictions. Schema is the result of psychologically active processes which require a great deal of mental effort. This schema will remain intact if predictions agree with the learner's experiences. If there is disagreement, cognitive restructuring may take place where the schema is revised or altered to accommodate the new experience. Such restructuring or re-organization of existing knowledge structures is appropriately termed "learning." However these schemas are highly resistant to change. The learner has a propensity to keep the schema intact, ignoring new sensory data. Thus, repeated attempts at disequilibriation or creating cognitive dissonance are required to force the learner to alter or modify the existing schema and "learn" new concepts or processes (Nussbaum & Novick, 1982; Saunders).

Learning as conceptual change. Within the framework of a constructivist epistemology, the learning of science can be viewed as the learner reorganizing knowledge structures so as to align those structures with scientific concepts. In other words, learning is restructuring ideas and concepts to revise misconceptions learners have constructed to align with the view of the conceptions accepted by the science community. Such a learning process has been termed conceptual change learning and several theories/models have been devised to explain such learning (Hewson, 1981; Posner, Strike, Hewson & Gertzog, 1982; Vosniadou, 1994, 1999, 2002). Many learner explanations or concepts of the natural world they experience are at variance with current scientific thought (Wandersee, Mintzes, & Novak, 1994). Such learner misconceptions about the natural world, labeled naïve or alternative conceptions, are the result of the cognitive activity of the individual learner acting on direct observations and perceptions and interacting with peers, culture, and social institutions (Driver et al., 1994; Staver, 1998; Wheately, 1991).

Posner and his colleagues (Posner et al., 1982) suggest that one form of conceptual change, referred to as assimilation, occurs when the current concept and the new concept to be learned are independently viewed by the learner as intelligible, plausible, and fruitful providing a basis for reconciling the concepts. Accommodation, the second form of conceptual change, requires the current concept to be discarded and replaced with the new concept sometimes referred to as conceptual exchange (Hewson, 1981; Hewson & Lemberger, 2000; Posner et al.). Central to both forms of conceptual change is the determination of the status of the concept—that is the new concept must be viewed as intelligent, plausible, and fruitful and there must be some dissatisfaction with the current concept. Such dissatisfaction in the learner is preceded by cognitive conflict or dissonance between the learner's alternative conception and a discrepant event which challenges that conception (Chinn & Brewer, 1993; Hewson & Lemberger). Desired learner outcomes in the science classroom are the assimilation and accommodation of scientific concepts including NOS.

Posner's et al. (1982) model also takes into account a learner's conceptual ecology. The naïve or alternative conceptions of the learner are connected to other concepts held by the learner in a kind of conceptual framework and are influential in determining whether or not the alternative conceptions will be replaced by a new scientific concept and to what degree (Hewson, Beeth, & Thorley, 1998; Hewson & Thorley, 1989; Posner et al.; Strike & Posner, 1992). Known as the learner's conceptual ecology, it is dynamic with different kinds of concepts and ideas interacting and leading to further development of ideas or conceptions. Thus, the learner's current conceptions form a framework which acts as a determinate regarding the status of new concepts and the movement of the new concept towards assimilation or accommodation. Cognitive features of the learner's conceptual ecology include (a) analogues and metaphors which may initiate new, intelligible ideas; (b) specific features of a concept which cause learner dissatisfaction which plays a part in selecting a concept's successor; (c) epistemological commitments including what makes an explanation successful and views of the character of knowledge; (d) metaphysical beliefs about the orderliness and symmetry of the physical world as well as teleology; and (e) knowledge of concepts in other fields (Posner et al.).

The cognitive ecology of the learner is an important component of the conceptual change process. The features of the conceptual ecology which may influence conceptual change are the epistemological commitments and metaphysical beliefs and concepts. Said features are implicit to the learner who is often unaware of them and are not necessarily open to direct empirical verification or reflection (Strike & Posner, 1992). Often the strength of the learner's commitment to the status of the concept and core concepts in the conceptual ecology determines the status of the new concept's intelligibility, plausibility, and fruitfulness and ultimately whether or not assimilation or accommodation take place (Beeth, 1998; Hewson & Thorley, 1989; Hewson et al., 1998). It should also be noted that in their model, Posner and his colleagues claim that intelligibility requires the learner to construct a coherent presentation of the theory which is internally represented within the individual in the form of images or propositions (Posner et al., 1982; Strike & Posner).

Conceptual change from a cognitive perspective. Posner et al.'s (1982) model proposes how conceptual change takes place in the learner but is less attentive to the origins of learner alternative conceptions and the transition of these conceptions into more correct versions. The model simply states that the learner possesses alternative conceptions and these interact with new concepts and may be revised or replaced as an outcome of learning. Vosniadou (1991) developed a cognitive perspective of conceptual change which addresses these unattended issues. From such a perspective, learners start science courses with naïve or initial theories of science. These naïve theories are more than naïve or alternative conceptions however. The conceptions are organized into a coherent framework theory replete with ontological and epistemological beliefs that makes it possible for the child to explain and function in the physical world (Vosniadou, 1999, 2002; Vosniadou & Brewer, 1994). Such frameworks are the result of active and creative efforts to establish mental coherence and while they do not constitute or meet the criteria of scientific theories, they are considered theories nonetheless as they are coherent and embedded in an entrenched belief system. The coherent and internally consistent framework theory acts as the determinate for rejecting or accepting alternative concepts and scientific concepts. Vosniadou (1999, 2002, 2003) suggests that learners form mental models when they must solve problems or explain phenomena. These mental models are built upon specific beliefs of the learners which in turn emerge from the framework theory. It is the framework theory complete with the axiomatic epistemological and ontological assumptions which is used to construct the learners' specific beliefs about how the world operates and the specific beliefs are called upon by learners to form mental models in problem-solving contexts.

The conceptual ecology of Posner et al. (1982), while similar in some points, is seen as lacking the cogency and coherency of Vosniadou's framework theory. For science learning to take place, the alternative conception that is targeted for replacement by a scientific concept must be seen in connection with other concepts. Thus, the process of conceptual change is not merely revising or replacing a concept but is more encompassing. Conceptual change involves changing the learner's naïve or initial conceptions and their framework theory to a scientific conception and theory. Such change is a slow gradual process involving the learner's mental models and the development of these models in three stages: naïve – to synthetic – to scientific. Aspects of science information are added to the learner's naïve or initial theory with the desire of threatening or destroying its coherency until it is restructured in ways to make it consistent with currently accepted scientific views (Vosniadou, 1991, 1994, 1999, 2003; Vosniadou, Skopeliti, & Ikospentaki, 2004).

Conceptual change must also be seen in the context of the continuity of cognitive development. Knowledge elements in prior knowledge or naïve theories are used to build more complex knowledge systems (Vosniadou, 1999, 2003; Vosniadou et al., 2004). The process of conceptual change is thought of as a gradual adjustment to the learner's conceptions and framework theory; each new adjustment begins the ground work for further adjustments but the end result is a substantial reorganization or change in the learner's specific beliefs and framework theory. This is why learning some science concepts, including the nature of science is very difficult for the learner. Scientific concepts may not be accepted by the learner because they are contradictory not just to the naïve conceptions of the learner but to the learner's epistemic commitments and metaphysical beliefs which form the framework theory. Thus, learning must include revising, deleting, adding, or suspending ontological or epistemological components of the learner's framework theory. Hence, conceptual change involves changes to the learner's presuppositions and beliefs (Vosniadou, 1991, 1994, 2002, 2003; Vosniadou & Brewer, 1994; Vosniadou et al., 2004).

A framework for developing preservice teacher understanding of NOS. The present study was guided by Vosniadou, (1991, 1994, 1999, 2003) conceptual change theory. Preservice teacher initial views of NOS are formed from their observations and experiences as they interact with other factors such as their formal education experiences. By means of observations and experience, the preservice teacher, as a learner, becomes aware of and appreciates various constraints regarding how the world operates (e.g., the work of gravity, orientations of up and down, etc.). These constraints become organized into ontological and epistemological presuppositions or beliefs. In turn these presuppositions will constrain the interpretation of future observations and experiences in the preservice teacher's construction of knowledge including scientific knowledge (Vosniadou, 1994, 1999, 2002, 2003). The lay culture, including parent understanding of scientific concepts, their epistemological commitments and metaphysical beliefs, various forms of media, and membership in various communities among others also influence and act as constraints on the development of preservice teachers' initial views of NOS (Vosniadou, 1994, 1999, 2002, 2003).

In addition K-12 school experiences cultivate the abilities and aptitudes of preservice teachers. These abilities or aptitudes as measured by ACT scores, cumulative high school and science course grade-point averages, and the types and numbers of high school science courses and other indicators may relate to various features within a teacher education program, including science content courses, science teaching methods courses, and pedagogy to promote a more informed understanding of NOS. Figure 1.1 represents the relationships among these general factors.

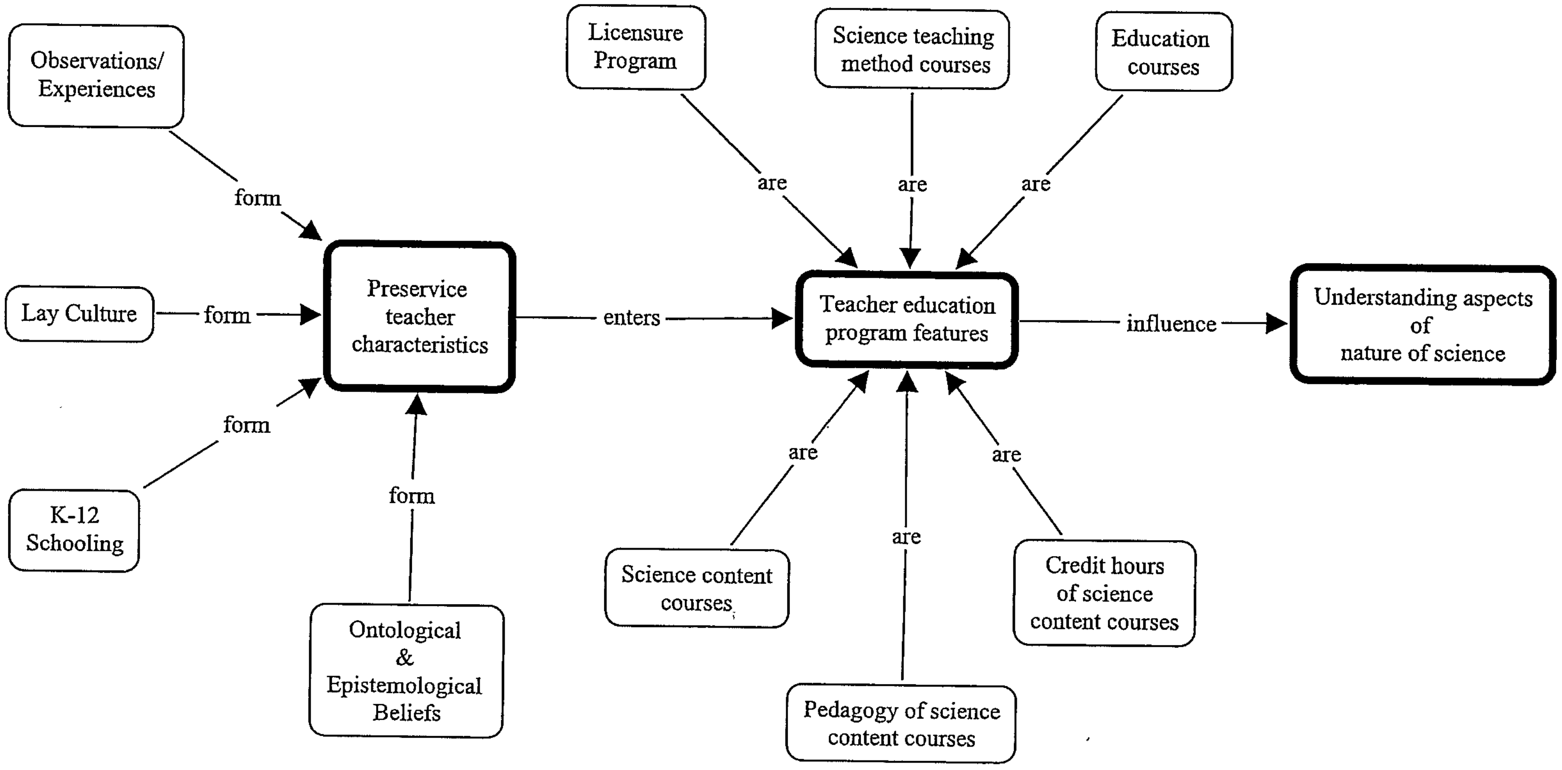

Figure 1.1. Developing preservice teacher understanding of NOS.

Research Methods Overview

The investigation was both descriptive and associational in its design using qualitative and quantitative research approaches to identify understanding of seven target aspects of NOS among students who were participants in the undergraduate teacher education program of a private, religious-affiliated Midwestern university. Participants selected for recruitment into the study were (a) enrolled as Early Childhood (EC), Middle Childhood – science concentration (MC-S), or Adolescent/Young Adult-science education (AYA-S) majors and (b) in year 4 of a traditional 4-year teacher education program. The instrument used to survey preservice teacher understanding aspects of NOS was the Views of Nature of Science Questionnaire Version C (VNOS-C) (Lederman et al., 2002) which contained 10 open-ended questions aligned with the 7 target aspects of NOS (see Appendix A). Validity of the VNOS-C questionnaire was affirmed in this study by interviewing 19 (50%) of the participants using the recommended semi-structured interview follow-up protocol (see Appendix B). A scheme for categorizing and scoring participant responses to the VNOS-C and interviews was developed using Stella Vosniadou's view of conceptual change in the learner (Vosniadou, 1999, 2002, 2003; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001; Vosniadou et al., 2004) and scoring rubrics or strategies from several studies which used the VNOS-B or VNOS-C instrument (Akerson, Hanson, & Cullen, 2007; Hanuscin, Akerson, & Phillpson-Mower, 2006; Schwartz, Lederman, & Crawford, 2004; Seker, 2004).

Several different records related to the participants formal high school and university experiences were collected for content analysis. Records of participant characteristics examined were high school and college transcripts, planning guides for the different teacher education program majors, and syllabi from required science teaching methods courses and science content courses. The Logic Model Process was used as a framework to classify participant characteristics drawn from examined records as antecedent or transaction predictor variables related to the NOS outcome variables. An exploratory analysis was conducted to determine the Pearson Product-Moment Correlation Coefficient (*r*) for pair-wise models of all participant characteristics compared to the scored aspects of NOS understanding. Fourteen of the 27 predictor variables were found to be significantly correlated ($r \geq 0.41$ at $\alpha = 0.01$) for at least one NOS outcomes variable. The fourteen predictor variables were selected for use in multiple linear regression analysis for each respective aspect of NOS to determine the amount of variance accounted for by antecedent and transaction variables for each NOS outcome.

Assumptions

Several assumptions underlie this study. First, it is assumed that the participants are representative of other students in the teacher education program at the university who are or will seek a teaching license which includes teaching science content. Second, the researcher assumes participants' responses to the VNOS-C questionnaire will be an accurate representation of their views. Third, the assumption is made that participants will provide detailed responses to the questions and will not give abbreviated responses due to affective factors (e.g., do not want to do the survey, desire to leave early, etc.). Fourth, it is assumed the high school and university transcripts are sufficiently free from error. Fifth, the researcher assumes that any lecture topics, activities, assignments, or projects listed in examined course syllabi were not omitted and additional activities, projects, etc. related to NOS were not added.

Delimitations

Subjects chosen for this study were year-four participants in an undergraduate teacher education program at an Ohio university. Participants in the study were enrolled in one of the following program majors: early childhood, middle childhood with science concentration, or one of five adolescent/young adult science education majors. Participants in these program majors are licensed to teach science content which includes NOS. Members of the teacher education program who were enrolled in the multi-age licensure programs (i.e. music education, physical education, health education, or Spanish education) were excluded. This study is interested in year-four participants, to describe their understanding of NOS and relating their understanding to features in the teacher education program. Thus, members not in year four of the teacher education program were also excluded.

The Views on Nature of Science-version C questionnaire (VNOS-C) was chosen to elicit participant understanding of NOS. The questionnaire is an open-response questionnaire and has the advantage of permitting respondents to state their views in their own words, not forcing a view from preselected choices which may not be representative of participants' views. The results of this investigation are used as an interpretive tool; ascertaining preservice teachers understanding of NOS for the purpose of identifying curricular and program features related to the promotion or impediment to understanding aspects of NOS. Participant responses are not used for summative purposes. Results are used to inform the teaching and learning of NOS in an Ohio university teacher education program.

Participants' high school and university transcripts were used to collect data regarding their formal education experiences and relate them to their understanding of NOS. This study chose to limit data to these experiences and not include other sources such as interest inventories or other aptitude tests such as the Armed Services Vocational Aptitude Battery. These sources were not available for each participant and the data elicited from these sources were viewed as ancillary. Syllabi from required education, science content, and science teaching methods courses were chosen for analysis to identify, describe, and compare experiences among participants. Assignments, projects, and activities not listed in the syllabi for these courses were not included as the researcher had access to some but not all.

This study examined participant characteristics regarding their high school curriculum and various features of the teacher education program as they relate to understanding various aspects of NOS. Other factors (see Figure 1.1) such as lay culture, ontological and epistemological beliefs, observations/experiences, etc. were excluded.

Definitions and Operational Terms

The use of the phrases "understanding aspects of NOS," "NOS outcomes," and "NOS aspects" instead of the phrases "understanding aspects of the NOS," "the NOS outcomes," and "the NOS aspects" throughout this study reflects the current state of affairs in the science education community regarding views of NOS. There is disagreement on exactly what the phrase "the NOS" means among philosophers of science, scientists, and science educators. However, there are aspects of NOS that all concerned agree upon and are not viewed as controversial (Abd-El-Khalick & Lederman, 2000a; Lederman et al., 2002; Matthews, 1994; Smith, Lederman, Bell, McComas, & Clough, 1997). These agreed-upon aspects represent some of the multifaceted views of what science is and how it operates. This list is not all inclusive thus the convention to refer to "nature of science" rather than "the nature of science." Several agreed upon aspects of NOS are the target aspects for this study and are emphasized in the science education reform documents (AAAS, 1990; NRC, 1996). These aspects are briefly described and include the abbreviations used in the study to represent them. The descriptions are based on the work of Lederman et al. (2002):

1. Empirical NOS (EMP): science is partially based on observations of natural phenomena using the senses or extensions of the senses.
2. Inferential NOS (INF): interpretations of observations.
3. Tentative NOS (TEN): scientific knowledge is subject to change as new observations, reinterpretations of extant evidence, etc. enter the commerce of the scientific enterprise.
4. Theory-laden NOS (THL): personal values, disciplinary commitments, educational experiences, etc. of scientists influence their work.
5. Social and Cultural NOS (SOC): the enterprise of science is influenced by the values and norms of culture and society.
6. Creative and Imaginative NOS (CRI): the production of scientific knowledge includes the use of human creativity and imagination.

7. Distinction between a scientific law and theory (DLT): theories and laws differ in function and are not hierarchal in their relationship (laws do not have a higher status than theories).

Terms used to describe participant understanding of NOS are informed, uninformed, and syncretic. Descriptions of the terms are as follows:

1. Informed understanding of aspects of NOS was defined as aligning with descriptions of specific aspects contained within *Science for All Americans* (AAAS, 1990) and the *National Science Education Standards* (NRC, 1996).
2. Uninformed understanding is defined as not aligning with these descriptions.
3. Syncretic is used by the researcher to describe an understanding of a specific aspect of NOS which has elements of both informed and uninformed understanding. It is used to represent understanding aspects of NOS which are neither uninformed nor informed. The term is often used in reference to religious or philosophical belief systems which are a combination of different, and at times contradictory, beliefs or practices. Syncretic describes the participant holding to both informed and uninformed beliefs, views, and understandings of a specific aspect of NOS simultaneously.

Participant characteristics are categorized as antecedents, transactions, or transaction outcomes. Descriptions of the categories are derived from the Logic Model Process used as a framework for this study (Cooksy, Gill, & Kelly, 2001; Julian, 1997; Renger & Hurley, 2006). Descriptions are as follows:

1. Antecedent: characteristics that a participant possesses or experiences completed prior to entrance into a specific program, formal setting, etc. In this

study, antecedents were characteristics that were descriptive of participant performance and experiences in high school.

2. Transactions: program activities or experiences intended to produce specific outcomes. In this study, specific course enrollment and declared major in the program were considered examples of transactions.

3. Transaction outcomes: Specific performance during transaction experiences, e.g., the grade earned in a specific course was considered as a transaction outcome.

Chapter 2: Review of Literature

The reform documents, *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1990) and the *National Science Education Standards* (National Research Council [NRC], 1996), are a call to action for the science education community to set as a goal for school science the development of students who are scientifically literate. Such literacy is viewed as a requisite for the citizenry of the technologically-advanced culture of 21st century America, enabling citizens by use of the content and process skills from the science disciplines (a) to engage in effective and sound personal decision making, (b) to engage in public discourse and social decision making regarding scientific and technological matters, and (c) to increase their economic productivity (AAAS; NRC). In addition to the preceding capabilities, a scientifically literate citizenry is essential to our national interests regarding defense technologies, economic growth, and solving regional and national problems that include science and technology components (AAAS; U.S. Department of Education, 2000). An essential feature to scientific literacy identified in these documents is the understanding of nature of science (NOS). A well-developed knowledge of science includes an understanding of what science is, what constitutes scientific knowledge, and how that knowledge is acquired and validated. Such understanding describes NOS. Nature of science may also be viewed as “governing rules” which delineate what is and what is not good science and how it is practiced (Clough, 2000).

These “rules” or aspects of NOS are described in both *Science for All Americans* (AAAS, 1990) and the *National Science Education Standards* (NRC, 1996). While these documents organize and describe NOS aspects in different ways, they do give parallel characteristics of the scientific endeavor. The characteristics described in both publications are reviewed in the following section; however, neither document provides an exhaustive list of the aspects of NOS but what is enumerated is generally accepted by the science and science education community.

Aspects of Nature of Science

Science for All Americans describes elements of NOS that are agreed upon by the scientific community and identifies elements that are requisite for scientific literacy (AAAS, 1990). These elements are nested within three broad subjects which describe the way science works. The scientific worldview, basic beliefs, and attitudes in science is one broad subject. The scientific world view is based on the assumption that the natural world is understandable and this understanding depends upon careful observation of phenomena. Consistent patterns within the natural world can be detected with the use of human senses or aids that extend the senses. Such observations are used to produce scientific knowledge. Yet this knowledge is subject to change with new or different observations and the possibility of such changes precludes the notion of scientific knowledge as absolute or complete.

Another broad subject, scientific inquiry, places the formulating and testing of hypotheses as the core activity of science. The validity of any scientific claim is settled by referring to the physical evidence. Observations, experiments, and predictions are means to generate such physical evidence. Imagination is often used to develop hypotheses and theories, and it is used to design tests for both. New scientific ideas can be generated by looking at old data in new ways. The terminus for collecting physical evidence is the construction of explanations for the observed natural phenomena; the formation of theories. However, those engaged in this process of observing and explaining are careful to identify bias and examine how such bias may unduly influence their activities of observing and interpreting data. A scientist's nationality, gender, socioeconomic status, training, etc., may influence how they interpret data, report data, or what data to consider in their explanations. The final broad subject, the scientific enterprise, describes science as a human endeavor, an enterprise that not only includes the individual dimensions of scientists, but also has social, cultural, and institutional dimensions. The activity of science will thus reflect social values and cultural norms which often directs science towards particular pursuits of natural phenomena.

The *National Science Education Standards* (NRC, 1996) presents criteria that are used by state departments of education and local school communities to describe the goals of science education and to judge the quality of science programs to achieve these goals. The *National Science Education Standards* recommend science content standards which include science as inquiry and the history and nature of science. These standards are organized into three grade-level bands: K-4, 5-8, and 9-12. The basic elements of these standards include: (a) science formulates and tests explanations of natural phenomena using observations, experiments, and models; (b) scientific knowledge is open and subject to modification; (c) scientific knowledge is constructed with the use of observations, evidence from investigations, logic, and creativity; (d) science differs from other knowledge forms by its use of empirical evidence to construct the best possible explanations about the natural world; and (e) scientists are influenced by personal beliefs, societal beliefs and values, and cultural norms.

The National Science Teachers Association (NSTA, 2000) issued a position statement on NOS echoing the tenets of NOS explicated in *Science for All Americans* (AAAS, 1990) and *The National Science Education Standards* (NRC, 1996). The declaration enumerates a number of premises important to the understanding of NOS. Premises listed include (a) scientific knowledge is both reliable and tentative, it can be modified in light of new evidence or reinterpretation of prior evidence and knowledge; (b) science is limited to naturalistic methods such as observations, rational argument, inference, skepticism, peer review, and repeatable results; (c) science is limited to naturalistic explanations of natural phenomena supported by empirical evidence; (d) the production of scientific knowledge requires creativity on the part of individuals engaged in the scientific enterprise; (e) the social and cultural context of the researcher and his/her experiences and expectations influences to some extent scientific endeavors; and (f) a primary goal of science is the formation of theories and laws. Laws are generalizations or universal relationships related to the way that some aspect of the natural world behaves under certain conditions. Theories are inferred explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws.

These premises along with the tenets of NOS from the *National Science Education Standards* (NRC, 1996) and *Science for All Americans* (AAAS, 1990) were organized as standards and adopted for use in the National Science Teacher Association's

Standards for science teacher preparation programs (NSTA, 2003). NCATE (n.d.) uses these standards to require teacher education programs to develop understandings of NOS among preservice teachers who will instruct students in elementary, middle school science, and high school science classrooms. In addition to knowing these aspects of NOS, preservice teachers are expected to communicate and assess their students' understanding of aspects of NOS (NSTA). Aspects of NOS identified in the NSTA standards that are of interest in this study and that have been examined in a number of other studies (Abd-El-Khalick & Lederman, 2000a; Lederman, 1992a; Lederman et al., 2002) include: (a) empirical NOS, (b) inferential NOS, (c) tentative NOS, (d) theory-laden NOS, (e) social and cultural NOS, and (f) creative and imaginative NOS. The distinction between a scientific law and theory is also included in the list.

To summarize – science is a way of knowing and explaining the natural world that differs from other ways of knowing. The nature of scientific knowledge and scientific inquiry is empirical in nature, using observations to make inferences and thus knowledge claims. Logic, imagination, creativity, and skepticism are necessary tools in the construction of scientific knowledge yet the process and final product of such knowledge building must respect the rules of evidence, always being consistent with observations and evidence. Scientific knowledge is characterized by its explanatory and predictive power. Yet such knowledge is also open to criticism and change; it is tentative knowledge having various degrees of uncertainty as warranted by the evidence. It is uncertain and tentative in that at any time new observations and evidence may require revisions to or outright rejection of specific claims. It is people who carry out activities that are called scientific endeavors and thus the scientific enterprise is subject to the personal beliefs of its practitioners. The process of science, practiced by people, is a part of society and therefore will be influenced by societal and cultural beliefs and will often reflect social values and viewpoints. However, the rules of science do call for methods that attempt to minimize some personal, cultural, or societal bias in the process of constructing scientific knowledge whether that bias is in the researcher, sample, method, or instruments. It also has ethical traditions such as peer review and honest and public reporting to protect society from malicious applications of the scientific process and knowledge claims.

Teacher and Student Understanding of NOS

Do students progressing through K-12 or undergraduate programs acquire appropriate or valid understanding of NOS? Do teachers in the elementary and science classrooms have appropriate understandings of NOS? Two critical reviews of the literature on NOS research provided a response to these questions. Lederman (1992a) and later Abd-El-Khalick and Lederman (2000a) suggested that students often do not have an informed or appropriate view of NOS. They cannot articulate many aspects of NOS which distinguish science from other disciplines or ways of knowing. It is also suggested that a student's understanding of NOS is influenced to a large extent by a teacher's understanding and classroom practices regarding NOS (Abd-El-Khalick & Lederman; Lederman). Often teachers hold alternative or poorly informed conceptions and recent research investigated attempts to improve such conceptions. Much of this research focused on factors which promote or positively influence teacher and student understanding of NOS. Many inquiries into such factors have examined the facilitation of NOS understanding in preservice teachers. The rationale behind use of these subjects may be that preservice teachers are more accessible for study and still in a formative period with regard to constructing scientific knowledge, including NOS. In-service science teachers are not as readily accessible, more entrenched in their classroom practices, and encumbered by a myriad of constraints to attempt to change their understanding of NOS and related classroom practices. Preservice teachers are thus a more pliable population in regard to researching and facilitating their understanding of NOS and in turn may be more successful in mediating student understanding of NOS. Results from such inquiries have uncovered several factors which may promote informed understanding of NOS among preservice teachers.

A more recent review of the literature conducted by Lederman (2007) supports the notion that science teachers do not possess adequate or informed views of NOS. Recent investigations challenge the long-held assumption that teacher conceptions of NOS influence classroom practices. If a teacher holds an informed understanding of NOS, it may not affect pedagogy in the classroom due to other constraints not necessarily related to the teacher's understanding of NOS. The aspects of NOS most often examined in the reviewed investigations are the creative and imaginative, theory-laden, social and cultural, and tentative aspects. Attention was given to the distinction between theories and laws, and to the relationship between observation and inference.

Alternative Conceptions of Nature of Science

Science for All Americans (AAAS, 1990) and the *National Science Education Standards* (NRC, 1996) describe various aspects of NOS and call for their inclusion in the curriculum to produce scientifically-literate students. Yet, the published literature reviews on the subject suggest that K-12 students, undergraduates, and science teachers have conceptions of NOS that are not consistent with the documents or the science (Abd-El-Khalick & Lederman, 2000a; Lederman, 1992a, 2007). Views inconsistent with the recognized viewpoints or knowledge claims of the science and science education communities have been termed alternative conceptions as articulated in the conceptual change literature (Wandersee et al., 1994). Alternative conceptions of students are not considered conceptual errors or misconceptions (Nussbaum & Novick, 1982). Rather, student alternative conceptions arise from the student attempting to make sense of the experienced world around them. When a student is given new information, that student uses existing schemas to interpret the new information. Using these schemas the student may interpret the new information or concept in a different way than intended by the teacher (Nussbaum & Novick). It is not a case of the student not understanding the concept as taught by the teacher but rather of the student understanding it differently (Hewson, 1981; Nussbaum & Novick). The alternate conceptions of students may be erroneous understandings, yet they are the product of the student's reasoning ability. They can be well-reasoned explanations or generalizations that contain some aspect(s) that is contradictory or inconsistent with the intended meaning of the concept (Schoon & Boone, 1998). The phrase alternative conception(s) will be used in subsequent discussion with regards to the conceptual change model and to describe participant understanding of the seven target aspects of NOS which are not aligned with informed understandings.

Alternative conceptions held by learners regarding NOS are many and varied. Those alternative conceptions of the aspects of NOS that are not consistent with NOS articulated in *Science for All Americans* (AAAS, 1990) and the *National Science Education Standards* (NRC, 1996) would include (a) the hierarchical view of the conceptual inventions of hypothesis, theory, and law (Abd-El-Khalick, 2005); (b) a view of science as objective, an activity that is unencumbered with the individual researcher's biases (McComas, 1996, 1998); (c) the perception of a surety or "absoluteness" to scientific knowledge (McComas, 1996, 1998); (d) the view that science is more procedural than creative and that experiments and tests prove scientific claims (Abd-El-Khalick & Akerson, 2004); (e) the view that there exists a universal procedure, a machine-like method of ascertaining scientific knowledge, that is sterile, boring, and matter-of-fact (McComas, 1996, 1998); (f) the view that scientific activities and the construction of scientific knowledge transcend social and cultural influences (Abd-El-Khalick, 2005); and (g) an unawareness of the underlying axiomatic assumption or presuppositions of science (Clough, 2000).

Preservice teachers have an hierarchical view of the conceptual inventions of hypothesis, theory, and law (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000a, 2000b; Clough, 2000; Lederman, 1999; Lederman et al., 2002; McComas, 1996, 1998; Ryan & Aikenhead, 1992). Preservice teachers believe that science starts with a hypothesis and over time with additional evidence or support it becomes a theory. Eventually enough evidence is garnered to warrant calling the theory a law. Preservice teachers fail to realize a hypothesis can progress into either a theory or law and have a misunderstanding of what constitutes a theory or law. This misunderstanding may be due in part to the misuse and hence alternative conception of the term "hypothesis." An "educated guess" is the mantra most often cited as a definition for hypothesis–but an educated guess of what? Hypotheses are not clearly delineated as generalizing observations, a generalizing explanation, or just predictions (McComas, 1996, 1998). Such an hierarchical view of hypothesis, theory, and law can lead to improper use of the terms and therefore alternative conceptions of these terms and their use in science. For example, if a law is seen as the end product in the hierarchy and theory is a transitory state of the concept before becoming a law, preservice teachers will see the theory as not well supported and still a work in progress, e.g., preservice teachers claiming evolution is just "a theory." Theories are often viewed as lacking any real scientific substantiation. Preservice teachers do not understand the proper use of theories to explain phenomena and to make predictions regarding new observations.

Preservice teachers see science as objective; an activity that is unencumbered with the individual researcher's biases (McComas, 1996, 1998; Ryan & Aikenhead, 1992). Preservice teachers fail to see that science is a human activity that is theory-laden; that is, the scientist brings previous knowledge, experience, educational background, and personal bias to the activity which in turn will influence inferences made from his/her observations. In addition to being theory-laden, science as an activity is committed to paradigms (Kuhn, 1974). These paradigms are views within the scientific community which address epistemological commitments and metaphysical beliefs and assumptions which in turn provide a framework which directs what kind of research questions can be asked and what constitutes criteria for evaluating and establishing scientific knowledge (Kuhn). Ryan and Aikenhead portray the objectivity of science in terms of the values of science. The core or constitutive values of science are objectivity, open mindedness, and unbiasness but these are referred to as "public science." Preservice teachers readily identify these features but are unaware of what Ryan and Aikenhead call "private science," where in the lab, bars, etc. scientists are more subjective, close-minded, and biased–but it is within this "private" context that science knowledge is developed and advanced. Preservice teachers fail to see the contextual values of culture, religion, and community mores as influencing and shaping science knowledge construction (Abd-El-Khalick, 2005; Lederman et al., 2002).

Preservice teachers perceive a surety or "absoluteness" to science knowledge (McComas, 1996, 1998). This alternative conception is based in part on a Baconian view of knowledge acquisition where observations can be subject to the process of induction to arrive at generalizations. It is through induction used within the confines of a general science methodology that we arrive at scientific truth. Nadeau and Desautels (1984) described this as a blissful empiricism, the view that all science knowledge is tied to direct observations or experimentation. Science knowledge is thus not viewed as constructed or tentative (Abd-El-Khalick & Lederman, 2000a; Lederman et al., 2001, 2002). However there is the "problem of induction" which confounds this view of surety and absoluteness (McComas, 1998). Preservice teachers are unaware of this problem and more importantly are unaware of the underlying assumption of uniformitarianism that must be employed to address it.

Preservice teachers see science as more procedural than creative and that experiments and tests prove scientific claims (Abd-El-Khalick & Akerson, 2004; Lederman et al., 2002; McComas, 1998). Such a view is referred to as "credulous experimentation" by Nadeau and Desautels (1984). Preservice teachers fail to see that induction alone is not capable of generalizing scientific knowledge, that abduction–the use of human imagination and creativity–is necessary to form inferences from observation and construct generalizations (McComas). Actually, the role of inference in constructing scientific knowledge is often misunderstood or ignored. Preservice teachers often fail to see the connection between observations and inferences. They allude to the idea that knowledge is discovered through direct observations, that knowing is seeing or that facts speak for themselves (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson). The roles of researcher observations, analysis, prior knowledge, reassessing, creativity, and imagination are often ignored by the preservice teacher in interpreting observations to construct scientific knowledge (Abd-El-Khalick; Abd-El-Khalick & Akerson; Abd-El-Khalick & Lederman, 2000a; Lederman, 1999; Lederman et al.; Ryan & Aikenhead, 1992).

Preservice teachers see a universal procedure, a machine-like method of ascertaining scientific knowledge, that is sterile, boring, and matter-of-fact (McComas, 1996, 1998). They view scientific inquiry as a step-by-step procedure rather than a set of activities and ways of thinking that can be applied in a variety of sequences or designs. Creativity's role in developing research designs, devising methods of data collection, interpreting data, and forming theories is often ignored. The scientific method is characterized as the right method, the only method or procedure by which to validate a claim as scientific. All research scientists must follow this procedure since it is viewed as distinguishing science from other disciplines (Abd-El-Khalick & Akerson, 2004; Lederman et al., 2002)

Preservice teachers are not cognizant of the social and cultural dimensions of science activity and the influence of culture and social forces on constructing scientific knowledge (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000b; Lederman, 1999; Lederman et al., 2002; McComas, 1998; Ryan &

Aikenhead, 1992). Scientific knowledge is seen as transcending culture, that it is insulated from the influence of cultural norms and societal values and institutions.

Finally, preservice teachers are unaware of the underlying axiomatic assumptions or presuppositions of science (Clough, 2000; Cobern, 2000; Mayr, 1997). Preservice teachers see science as a straight forward activity of observing and testing, yet fail to see this empirical way of knowing as resting upon key untestable assumptions without which science as a way of knowing could not operate.

Conceptual Change Theory and Alternative NOS Conceptions

Why do preservice and in-service science teachers have such alternative conceptions of NOS? The conceptual change model of learning provides a framework by which to explore this question. In particular the work of Stella Vosniadou is most illuminating. The process of learning science requires learners to restructure their previous knowledge or intuitive knowledge and resulting mental models to conform to currently acceptable scientific concepts *(*Vosniadou, 1991, 1994, 1999, 2002, 2003; Vosniadou & Brewer, 1994; Vosniadou et al., 2001; Vosniadou et al., 2004.) Often in this conformation process the mental models proceed through three stages: (a) the intuitive or naïve model, (b) the synthetic mental model, and (c) the scientific mental model. The intuitive or naïve model is based upon experience with everyday phenomena with no influence from scientific models. Also called an initial model, it relies exclusively on the learner's interpretation of experience derived from everyday observations. The synthetic mental model reflects the stage where the beliefs of the naïve model are changed in such a way that the learner can hold on to them without contradicting an accepted new scientific model. The learner attempts to assimilate scientific information into an existing model, trying to reconcile scientific explanations with their observations. The synthetic mental model represents the learner's attempt to assimilate scientific information or new information from schooling into an existing mental model. The scientific mental model of the learner agrees with the scientific view and is the product of the learner changing his or her concepts.

Learning science within this view is a slow, gradual process where aspects of science information are added to the student’s initial model threatening the coherency of his or her specific or framework theory forcing the student to develop a synthetic model which is a transitory state between the naïve mental model and the scientific mental model (Vosniadou, 1999, 2002, 2003; Vosniadou et al., 2001; Vosniadou et al., 2004). Conceptual change requires that the new science information act in a way to challenge the beliefs of the specific theory or axiomatic assumptions of the framework theory and requires revision, elimination, addition, or a suspension of said beliefs or assumptions. Such a change lifts the constraints of the framework and specific theories placed upon the formation of the mental model, thereby changing the mental model in such a way that it conforms to the scientific model. From this view, it is easy to see why schooling is many times ineffective in developing appropriate understanding related to aspects of NOS. Alternative NOS conceptions arise from student observations and experiences with the surrounding world. They are constructs developed to make sense of his or her world. However, these alternative conceptions are not segregated concepts or ideas which are superficially connected. Rather, these alternative conceptions are organized along with other concepts of the learner into a coherent and internally consistent framework which will act as the determinant for rejecting or accepting alternative concepts and scientific concepts (Vosniadou, 1999, 2002, 2003; Vosniadou et al., 2001; Vosniadou et al., 2004).

Posner et al. (1982) see an analogy between conceptual change in individual students and the development and change of concepts in the scientific disciplines. Describing and using Kuhn's (1974) "normal science" and "revolutionary science," a model of conceptual change in the student was proposed. Posner et al. start from the premise that the learning of new concepts takes place within the context of the learner's current concepts. When a student is confronted with a new concept, she or he must rely on current concepts to organize her or his investigations and understanding. At times, however, the learner's new concepts are insufficient to provide an understanding of the new concept or as Hewson (1981) describes it, an existing conception is challenged by a new concept.

Learning science is understood to involve a process of conceptual change that is analogous to "normal" science and "scientific revolution" (Posner et al., 1982; Strike & Posner 1992). Assimilation or Hewson's (1981) conceptual capture is analogous to normal science where existing concepts are adequate to interact with new phenomena. A student may experience a scientific revolution where his or her current concepts are inadequate for developing an understanding of a new concept. This requires the student to replace or reorganize these central concepts, a radical form of conceptual change called accommodation by Posner et al. and conceptual exchange by Hewson. Central to both forms of conceptual change is the determination of the status of the concept – that is, the new concept must be viewed as intelligent, plausible, and fruitful and there must be some dissatisfaction with the current concept (Hewson; Posner et al.; Strike & Posner). The status of the concepts will determine if assimilation or accommodation can proceed for the learner. Like Vosniadou (1999, 2002, 2003), Posner et al.'s process of conceptual change is thought of as a gradual adjustment in one's conception; each new adjustment begins the ground work for further adjustments but the end result is a substantial reorganization or change in a student's central concepts and conceptual ecology. The use of instructional strategies using conceptual change approaches has been suggested for NOS instruction (Akerson, Abd-El-Khalick, & Lederman, 2000; Meichtry, 1992)

Factors Which Influence Understanding Nature of Science

Explicit and implicit instructional strategies. A number of instructional methods and strategies which influence and promote preservice teacher understanding of NOS have been identified and investigated. The effectiveness of such strategies appears to be a function of a more general strategy – whether they are embedded in an implicit or explicit approach to instruction (Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000b; Bell, Lederman, & Abd-El-Khalick, 1998; Lederman, 1992a, 1999; Lederman et al., 2001, 2002). Implicit attempts to teach NOS assume that students and preservice teachers learn NOS by "doing science" as they engage in hands-on activities, inquiry, or process skill instruction. Learning NOS is a secondary outcome that arises from the context of learning other content or process skills (Abd-El-Khalick & Lederman, 2000b; Lederman et al., 2001). Thus, as a consequence of science instruction it is expected that learners would develop understandings of NOS without calling attention to NOS concepts.

Contrary to the implicit approach, aspects of NOS are intentionally targeted in an explicit approach. Student and preservice teacher understandings of NOS are considered primary learning outcomes and constitute independent topics in the curriculum with specific instructional objectives (Abd-El-Khalick & Lederman, 2000a; Lederman et al., 2001; Scharmann, Smith, James & Jensen, 2005). Aspects of NOS are taught explicitly or made explicit within the context of teaching other content or process skills. Teaching NOS is to be well planned and articulated as a cognitive learning outcome, not merely assumed to be a by-product of other instruction.

Abd-El-Khalick and Lederman (2000a) examined a number of studies which attempted to ascertain the effectiveness of either the implicit or explicit approach. A cursory review of the studies revealed that an explicit approach achieved significant results compared to those employing implicit approaches. However, the authors are quick to point out that the statistically significant gains reported were too small to be of practical significance and understandings of NOS were still limited and considered uniformed in many aspects. Nevertheless, Abd-El-Khalick and Lederman still suggested and advocated the effectiveness of an explicit approach over an implicit one. A more detailed analysis of some studies reviewed by Abd-El-Khalick and Lederman and others is provided.

Meichtry (1998) reported the development of an elementary science methods course designed to integrate NOS with other course content by explicit means. Participants (*n* = 67) were senior undergraduates and graduate students seeking teacher certification. They were enrolled in one of three elementary science methods courses which used the same syllabus. All participants were required to complete a minimum of three science courses, each with a laboratory component, prior to enrollment in the science methods course. At the start of the course, participant views regarding four dimensions of the nature of scientific knowledge were measured by using The Modified Nature of Scientific Knowledge Scale (MNSKS) developed by the author. During the course, participants completed a number of activities associated with the explicit teaching of NOS. These included (a) participants teaching a learning cycle lesson on science content to peers and elementary students and writing a reflective analysis about what was learned about science and science teaching; (b) participants conducting a long-term research experiment and writing a research report, share the results with peers, and write a reflective analysis summarizing what was learned about the nature of scientific inquiry; (c) participants discussing and writing a response to the question “What is science” at the start of the semester and part of the final semester assessment; and (d) participants completing a quiz on NOS. At the conclusion of the course participants views on NOS were measured again using MNSKS. Pre/post test analyses with paired sample comparison *t*-tests were done on participant responses to the MNSKS. Qualitative analysis was completed on participant responses to the activity “What is science” at the start and finish of the course.

Reported results indicated participants started with incomplete understanding of NOS as measured by the MNSKS instrument. Participants did develop significantly greater understanding about NOS at the completion of the course and were more inclined to relate the teaching of NOS to the elementary science classroom. Meichtry (1998) suggests that integrating NOS concepts with teaching strategies has the potential to develop more complete understandings about NOS among preservice teachers. Such an integrative approach may overcome the challenges cited by Arons as reported by Meichtry (n.d.). The challenge is that instructional efforts to cultivate scientific literacy in the K-12 and undergraduate classroom are often hampered by (a) waves of technical jargon associated with science – a new vocabulary that has no contextual meaning for the audience – inundate the student and (b) the pace of teaching is blistering. This challenge of content coverage obsession precludes any meaningful reflection on the aspects of NOS by the student and hence any construction of such knowledge.

While an explicit and integrated approach to teaching NOS produced immediate improvement in preservice teacher views of NOS in Meichtry's (1998) investigation, there is some question as to the long-term outcome. Akerson, Morrison, and McDuffie (2006) examined a cohort of 17 participants in an elementary science teaching methods class. The participants were pursuing a masters in teaching degree and each completed 12-15 science credits. At the start of the course the VNOS-B questionnaire was used to assess participant understanding of aspects of NOS. A pedagogical component of the course was the explicit-reflective teaching of aspects of NOS. During the course participants (a) engaged in weekly readings which included selections related to NOS conceptual development, (b) performed weekly hands-on activities to reinforce their understanding of key scientific concepts – during the activities the instructor made explicit references to NOS, (c) engaged in 6 hours of instructional activities designed to explicitly address the seven target aspects of NOS, and (d) participated in oral and written activities that encouraged preservice teachers to reflect on NOS aspects. At the conclusion of the course and 5 months after the course, participants responded to the VNOS-B questionnaire.

Results from the study showed an initial improvement in preservice teachers understanding of NOS. Akerson et al. (2006) determined that participants could "talk the talk” (p. 209) and articulate basic ideas on the aspects of NOS. But deeper internalizing of concepts, constructing notions on their own, and being able to provide examples on their own did not occur. After 5 months, several participants reverted back to their prior uninformed views. Using Perry’s scheme, Akerson et al. analyzed participants’ cognitive levels of understanding. Based on the analyses it was suggested that (a) the use of meta-cognitive teaching strategies may be useful to develop preservice teacher understanding of aspects of NOS and (b) the newly formed NOS conceptions should be contextualized in course and instructional activities.

Schwartz et al. (2004) provided additional support for the position that explicit and guided attention to and reflection on NOS enhances student and preservice teacher understanding of NOS. The authors studied developments in NOS conceptions during a science research internship course for 13 preservice secondary science teachers. In addition to the research component, the course included seminars and journal assignments related to developing preservice teacher understanding of NOS. Preservice teacher NOS views were assessed pre- and post-internship using the VNOS-C. Schwartz et al. concluded that the science research internship was successful in helping to strengthen and deepen these preservice teachers’ conceptions of NOS. Three factors were identified as most influential in the development of conceptions of NOS: (a) explicit opportunities for reflection through the journals and discussions, (b) the authentic context of the research setting, and (c) the reflective perspective of the intern. The authors further claim that the results refute the notion that just “doing science” is sufficient for one to develop proper conceptions of NOS.

Akerson et al. (2000) examined the influence of an explicit, reflective approach to NOS instruction in an elementary science methods course on preservice teacher understanding of seven aspects of NOS. Participants were 50 students enrolled in two sections of an elementary science methods course. Twenty-five undergraduate students (23 females and 2 males) were enrolled in the first section and 25 graduate students (22 females and 3 males) were enrolled in the second. The two sections were similar in structure and requirements using the same readings, activities, and assignments. The course assignments included an in-depth study of science content and the in-class activities were content-based explorations designed to help the preservice teachers experience a variety of teaching methods and reinforce their understandings of key science concepts. The emphasis for the course was developing teaching skills and strategies in the context of the further development of science content knowledge. However, the preservice teachers engaged in different activities the first 6-hours of class that explicitly addressed the seven target aspects of NOS and reflected on these activities throughout the semester in relationship to the activities focused on science content. Classroom discussions and written reflections included prompts relating NOS to science content activities and class readings. Pre-and post-course measurements of participants understanding of NOS were made with an open-ended questionnaire targeted to seven aspects of NOS.

The results of this study indicate that the explicit-reflective, activity-based approach to NOS instruction employed in the science methods course was effective in enhancing participant preservice elementary teachers' views of NOS. Based on their findings Akerson et al. (2000) suggested that preservice teachers should be provided opportunities to examine their views of NOS early and often. Such opportunities may provoke preservice teachers to become dissatisfied with their NOS views, and thus generate an incentive to adopt more current conceptions of NOS. Bell, Blair, Crawford, & Lederman (2003) corroborated Akerson et al. findings in a related study. Akerson et al. argue that a conceptual change model coupled with explicit-reflective NOS instruction might be more effective in developing proper understandings of the seven target aspects of NOS.

In another study of an explicit approach to NOS instruction, Akerson et al. (2007) investigated the impact of a 2-week summer workshop on fourteen K-6 elementary teachers. The professional development workshop addressed two areas: (a) developing the knowledge of physics concepts and (b) teaching techniques that explicitly emphasized NOS and scientific inquiry. An explicit-reflective approach was used to facilitate participants developing informed understandings of the empirical, inferential, tentative, theory-laden, social and cultural, and creative and imaginative aspects of NOS. Participant views of these aspects of NOS were assessed pre-and post-workshop using the Views of Nature of Science Elementary School Version 2, a modified VNOS-C questionnaire. Akerson et al. found that the majority of participants changed their ideas about the target aspects of NOS and moved closer to informed understandings. The use of inquiry that is connected to an explicit-reflective NOS approach facilitated such changes. However, it was noted that misconceptions about NOS persisted among many of the participants and the view of the Akerson et al. was the workshop was just a start. Efforts to develop accurate conceptions of NOS must be sustained and on-going in order to help teachers develop these accurate conceptions of NOS and incorporate them into their classrooms.

An explicit-reflective intervention was used by Hanuscin, et al. (2006) to enhance undergraduate teaching assistants' conceptions on seven aspects of NOS. The teaching assistants taught a 3-hour laboratory session for the "Physical Science for Elementary Teachers" course. The course included NOS objectives and the laboratory component was viewed as another opportunity to facilitate preservice teacher understanding of NOS. Thus, the teaching assistants' conceptions of NOS were examined and an intervention designed to promote their understanding of NOS. Teaching assistants' conceptions of NOS were measured pre-and post-intervention using the VNOS-C questionnaire. The intervention consisted of (a) introducing NOS as a goal of science education, (b) completing and reflecting on NOS laboratory activities, (c) discussing weekly aspects of NOS reflected in the laboratory investigations in the course, and (d) discussing preservice teachers' responses to the VNOS-C during weekly meetings. Results indicated all 9 teaching assistants changed their views on at least one NOS aspect, with 3 of the teaching assistants demonstrating a shift in views on four NOS aspects. In several cases, the internalization of the importance of NOS as an instructional goal was evident to the researchers. The investigators argued that the explicit-and-reflective interventions employed contributed to these observed changes by providing opportunities for the teaching assistants to (a) clarify the meaning of NOS terms, (b) ascertain the validity of NOS as relevant to constructing scientific knowledge, and (c) construct a coherent framework of NOS by relating the various aspects to each other.

Regarding the use of explicit NOS curriculum materials Meichtry (1992) compared the middle school BSCS curriculum to traditional middle school science curriculum and textbook regarding gains in understanding NOS. A non-equivalent control-group design was used to compare sixth, seventh, and eighth grade student views on NOS. One school (*n*=1004) used the BSCS curriculum and the other (*n*=604) used the traditional curriculum and served as the control. The BSCS curriculum design used a more explicit representation of NOS in the (a) organization of the science content, (b) amount of science content taught, (c) instructional methodology used by teachers, and (d) curriculum materials. The modified version of The Nature of Scientific Knowledge Scale (MNSKS) developed by Rubba in 1977 was used to measure student views on four subscales of NOS. Results indicate there was no significant difference on NOS views between students using the BSCS curriculum and those using the traditional curriculum. It was found that the BSCS group decreased on two of four subscales and was significantly less than the control students in one measure. The author suggests that the use of a science curriculum designed to develop student understandings of NOS does not guarantee it will happen. Rather, to be successful, the curriculum must also employ constructivist approaches to teaching. Specifically it is recommended that (a) there must be an explicit representation of all aspects of NOS in the curriculum and instructional method used and (b) conceptual change models of instruction must be used on the aspects of NOS targeted in the classroom.

Teacher behaviors. Recent research has identified several factors which may facilitate preservice teacher understanding of NOS. Using case studies, Lederman (1999) found that classroom practices were not necessarily influenced by teacher conceptions of

NOS. Rather it was the intentions and goals of the teacher regarding the teaching of NOS that were most influential. The degree to which teachers viewed the importance of NOS as a cognitive learning outcome and included explicit NOS instructional objectives determined the level of student acquisition of the understanding of NOS. Based on these findings, Lederman suggested that "promoting the internalization of the view that the nature of science is an important instructional objective …" (p. 927) for teacher education programs and K-12 schooling.

Related to Lederman's suggestion of the internalization of NOS as an important instructional objective, Lotter, Singer, and Godley (2009) described the influence of a secondary science methods program with two mentored practicum experiences on secondary science preservice teachers' views and enactment of NOS and inquiry-based instructional practices. The study sample consisted of 9 secondary science preservice teachers enrolled in a master's level teacher preparation program. The course was organized around five major pedagogical principles which included inquiry and NOS. Two teaching field experiences were incorporated into the class and were separated by a time interval of several weeks. An explicit-reflective approach to teaching NOS was emphasized in the class which included daily and weekly reflections by the preservice teachers on one of the five major pedagogical principles emphasized in the course. The preservice teachers' views on aspects of NOS were measured at the start and again at the conclusion of the semester using the Views of Scientific Inquiry (VOSI) questionnaire. All participants developed more informed understandings of NOS based on the pre- and post-course responses to the VOSI. The researchers concluded that the study showed the positive influence of cycles of practice teaching and guided reflections on preservice teacher views of NOS.

Though the study indicated that the preservice teachers improved their NOS understanding, they did struggle to incorporate explicit NOS instruction into their unit plans for their field experience. The researchers surmised that this may be due to the exclusion of NOS from the state academic standards. Thus, to the preservice teachers, NOS was not as vital a goal as teaching inquiry and the prescribed state content standards. Other reported findings were that the preservice teachers described leaving NOS instruction for the last few minutes of class or getting too involved in other teaching duties to attend to NOS instruction. The researchers found that the preservice teachers in the study that enacted NOS instruction more consistently were the ones that explicitly planned for NOS discussions or activities and had strong classroom management and content knowledge skills. This finding, suggests Lotter et al. (2009), is consistent with previous research that shows beginning teachers have difficulty incorporating new instructional strategies given their focus on classroom management and content instruction. Abd-El-Khalick, Bell, & Lederman (1998) and Bell, Lederman, & Abd-El-Khalick (1998, 2000) suggest that classroom practices of teachers and their beliefs about NOS are not always directly connected. Teachers often understand the aspects of NOS but do not necessarily address the aspects explicitly in the classroom. The lack of attention to explicit NOS instruction was attributed to (a) teachers viewing NOS instruction as a minor objective, (b) the lack of resources and experience teaching NOS, and (c) lack of planning time (Abd-El-Khalick et al., 1998).

Lederman (1992b) commenting on the role and influence of the teacher in developing student understanding of NOS identified a number of teacher behaviors linked to such understandings. Effective teachers with regard to fostering more accurate conceptions of NOS: (a) stressed higher level thinking skills, (b) used problem solving instructional methods, (c) used inquiry oriented instruction, and (d) frequently used higher level questioning within a supportive and risk-free environment. Lederman also advised against the unqualified mixing of colloquial and scientific language in classroom discourse. Teachers were recommended to carefully select language used to convey scientific meanings and give explicit attention to student language and implied meanings during classroom discourse to identify misuse of terms and student misconceptions.

Lederman et al. (2001) assessed the effectiveness of research-based revisions to an existing Master of Arts in Teaching (MAT) program in an effort to improve preservice teacher abilities to facilitate student understanding of NOS. Another goal of the research was to further test the common assumptions that (a) to teach NOS, teachers must have an adequate understanding of NOS and (b) teacher views of NOS would translate directly to their classroom practice. Prior research suggests that neither assumption was valid and there may be a variety of factors including classroom management and organization, local and state curricular constraints, and general teaching effectiveness which invalidate the stated assumptions (Lederman, 1999; Lederman et al., 2001, 2002). The treatment or intervention in the study consisted of four changes to the MAT program based upon previous research. The changes were (a) a new course added at the beginning of the program that focused on NOS and inquiry, (b) the requirement of preservice teachers to prepare and teach two lessons on one or more aspects of NOS and complete resource cards on teaching NOS, (c) the requirement of preservice teachers to serve in a science education internship where they worked in a laboratory with a practicing scientist and engaged in seminar and reflective writings on NOS, and (d) the requirement for preservice teacher participants to develop and assess NOS objectives in their student assignments.

The participants completed the VNOS-C questionnaire (an open-ended response questionnaire) and engaged in semi-structured interviews, both of which were used to produce a profile of their NOS views. Observations from the methods course, fall internships, and informal discussions with preservice teachers and their field supervisors along with biographical information from student files were used to formulate participant profiles. The revisions or treatment of four program changes as a whole were used with preservice teachers to emphasize aspects of NOS in a variety of ways.

Results of the study suggest that (a) preservice teachers increased their explicit attention to NOS with respect to planning, classroom practice, and instructional practice due to the intervention; (b) strong science subject matter knowledge and knowledge of NOS were both essential to improving preservice teacher inclusion of NOS in classroom instruction (however, having such knowledge does not guarantee that preservice teachers will address NOS frequently or explicitly); and (c) preservice teacher views and beliefs about the importance of NOS and their intentions to teach NOS influenced classroom instruction, corroborating previous findings.

Learner behaviors. Abd-El-Khalick and Akerson (2004) sought to assess the effectiveness and the factors mediating the effectiveness of an explicit reflective NOS instructional approach which uses a conceptual change framework for preservice elementary teachers’ views on NOS. Specifically, the research questions were (a) what is the influence of using an explicit reflective teaching strategy that satisfied conditions for learning for conceptual change of preservice teacher views of certain aspects of NOS and (b) what factors of the participants’ learning ecologies facilitate or hinder the development of their NOS views in the context of the study? Participants in the study were administered the VNOS-B questionnaire (an open-ended questionnaire with seven items) prior to the intervention of the methods class and at the conclusion of the methods class. At the end of each questionnaire administration, 10 participants were randomly placed into interview groups and asked to clarify and explain their responses. Participants then engaged in 11 activities designed to direct participants to examine their own views of NOS and evaluate their status.

Three factors were tentatively identified that mediate the development of NOS understanding. The first factor was a motivational factor, referred to as “internalizing the importance of NOS,” related to focus group members’ perceptions of the importance and utility value of learning and teaching NOS. Preservice elementary teachers showing significant growth in their NOS understanding showed an initial commitment to learning about more accurate views compared to the minimum-growth preservice elementary teachers. They believed it was their responsibility to help their students develop informed views of NOS. This finding is consistent with Lederman’s (1999) research results.

The second factor identified was a cognitive factor, referred to as “deep versus surface orientation to learning,” related to focus group members’ attempts to seek a consistent informed view after initial dissatisfaction with their own views of NOS. Preservice elementary teachers who showed significant growth in their NOS understanding examined their own NOS views and sought alternatives that were consistent and congruent with informed views presented during the intervention. Also, the same preservice elementary teachers who showed significant growth in their NOS understanding attempted to be consistent in the use and meanings of key terms used in discussing NOS and were able to better distinguish between everyday and more accurate meanings of these key terms. Such cognitive attempts were not present in preservice elementary teachers who showed minimal growth in NOS understanding.

The third factor was a cultural factor, referred to as “global worldviews,” interacted with focus group members’ development of their NOS understanding. Preservice elementary teachers who demonstrated minimal growth in their understanding of NOS had (a) a religious world view, (b) viewed religion and science to be in opposition, and (c) attempted to apply criteria of credibility associated with religion to the domain of science. Preservice elementary teachers who showed significant growth in their NOS understanding were able to differentiate between religious and scientific ways of knowing. Scharmann et al. (2005) investigated such global worldview factors in explicit attempts to teach aspects of NOS in the context of a science education methods class. Their results were interpreted as suggesting that understanding NOS is promoted using an explicit approach which creates cognitive dissonance on the part of the preservice elementary teachers regarding their holding of alternative conceptions. The careful and thoughtful discussion of preservice elementary teachers’ global worldviews and multiple opportunities for preservice elementary teachers’ reflection were suggested as factors which may promote understanding NOS.

The role of learner self-regulation in conjunction with an explicit, reflective nature of science intervention was investigated by Peters (2009) to determine if such an approach could increase both NOS knowledge and content knowledge. Two-hundred and forty-six grade 8 students from 12 intact classes over a period of three years were instructed using either an implicit approach (n = 114) or an explicit approach (n = 132). All classes were taught by the same teacher who was trained in the delivery of the intervention and who was mindful of the possibility of contamination. All students, regardless of the approach used in the class, were given identical content knowledge tasks. But each class, depending on the approach used, was given a different way to develop NOS knowledge. The explicit group was given a self-regulatory training model that set goals for the students regarding their performance for a selected aspect of NOS. Members of the explicit group were given checklists and questions to self-monitor their progress in aligning their inquiry activities to ideas about NOS. The implicit group learned about NOS implicitly through the inquiry activities and was given additional content questions to account for equal time-on-task. Student understanding of the aspects of NOS was measured pre-and post-intervention using the VNOS-B questionnaire.

Results indicate that students in the classes receiving the explicit approach with self-regulation instruction significantly outperformed those in the implicit approach classes on four of the aspects of NOS that were specifically taught. There were no significant differences between the two groups regarding their views on the three aspects of NOS not addressed during the 6-week intervention. Peters (2009) concluded that explicit-reflective methods of teaching NOS are one way to develop student understanding of NOS and there is some evidence that self-regulation can be used to make NOS explicit, resulting in increased NOS knowledge as well as science content knowledge. The study did not address the degree to which self-regulation instruction or explicit-reflective approaches accounted for the gains. Self-regulation may play a role in developing student NOS understanding or it may not. The study did not or was unable to make such a determination. Akerson et al. (2006) suggested that while immediate gains were made regarding participant understanding of NOS they were not necessarily retained. Caution must be exercised in using Peters' findings.

Summary

K-12 students, preservice elementary and secondary science teachers, and in-service elementary and science teachers have views on aspects of NOS that are not consistent with accepted views. In addition to their views not aligning with those articulated in the science education reform documents, persistent misconceptions or alternative conceptions are held. The source of such alternative conceptions and their resistance to change is explained by conceptual change models of learning. Such models suggest that alternative conceptions are not superficially held. Rather they are based on a learner's previous experiences which have been granted acceptance and high status by the interpretative framework constructed by the learner to make sense of the world. To change the alternative conception to an appropriate conception requires modifications to the learner's interpretative framework which explains the persistence of these alternative conceptions.

Various approaches to facilitate changing learner alternative conceptions to appropriate NOS conceptions have been investigated. Explicit-reflective approaches incorporated conceptual change teaching strategies and included (a) explicit NOS instruction in the context of scientific inquiry; (b) the explicit integration of NOS conceptions with other science content; (c) explicit NOS instructional activities and assignments; and (d) various and repeated learner reflection activities on NOS with regard to course work, teaching experiences, and research experiences.

Investigations have identified other factors associated with developing appropriate NOS understanding among learners that have been used in conjunction with explicit-reflective approaches. The degree to which a learner internalizes the importance of NOS, the learner's orientation toward learning, the ability of the learner to differentiate between science and other ways of knowing, and the learner's use of self-regulation strategies may contribute to the degree that the learner's alternative NOS conceptions transition to appropriate conceptions. The role of teacher behaviors in developing appropriate NOS conceptions has been investigated to a lesser extent.

Chapter 3: Methodology

The purpose of this study was to examine understanding aspects of nature of science expressed by preservice teachers enrolled in the teacher education program at a Midwest liberal arts university. Further, it sought to identify factors or variables and their relationship to participants' understanding aspects of nature of science (NOS). The research questions addressed in the investigation were:

1. What understanding do the participants of the teacher education program at a Midwestern liberal arts university have of aspects of nature of science near the completion of their licensure programs?
2. Would teacher education participants' understanding aspects of nature of science align with an informed, syncretic, or uninformed understanding of nature of science?
3. What variables or factors discriminate between the different levels of understanding aspects of NOS among teacher education participants?

It was the intent of this investigation to identify a small set of variables or factors that are related to promoting the development of an informed understanding of target aspects of NOS among preservice teachers. This research is in part an evaluation of the institution's success in preparing participants with an appropriate or informed understanding of aspects of NOS. If teaching aspects of NOS is a vital component of science literacy, it is necessary to identify teacher education program factors or variables which may promote preservice teacher understanding of these aspects. Such knowledge would be useful to the faculty in the teacher education program in developing curriculum and program features to address the development of preservice teacher understanding aspects of NOS. The characteristics within the teacher education program which are experienced by the participants are not manipulated by the researcher and participants' characteristics and their understanding aspects of NOS are examined ex-post facto. Establishing causation between program variables and NOS outcomes is not possible with ex-post facto research and is thus not the aim. However, exploring the relationship between variables of the program and the outcomes of understanding aspects of NOS will perhaps yield results which may be viewed as evidence to suggest that the inclusion of different strategies, methods, etc. in the teacher education program or modifying particular program elements may result in greater preservice teacher understanding of NOS aspects.

Accredited teacher education programs are engaged in a continual cycle of assessing the degree to which they meet their stated goals and outcomes. The organizational framework which guides this study and the methods it employed may provide direction and guidance for on-going and long-term evaluations of the teacher education program regarding participant NOS outcomes.

Research Design

The investigation is both descriptive and associational in its design using qualitative and quantitative research approaches to generate data to answer the research questions. The thrust of using qualitative methods is to describe teacher education participant understanding aspects of NOS and determine if their understanding aligns with what experts call informed or uninformed views or if their understanding is better characterized as syncretic – demonstrating some understanding yet holding on to misconceptions or contradictory beliefs regarding aspects of NOS. Descriptive studies include summarizing the characteristics of individuals or groups and are often considered the starting point for most research (Fraenkel & Wallen, 2003). Qualitative data as described by Patton (2002) are "detailed descriptions of situations, events, people, observed behaviors, direct quotations from people about their experiences, attitudes, beliefs, and thoughts … (p. 22). The starting point for this investigation was the description of participant understanding of aspects of NOS and involved the collection of qualitative data to interpret participant views.

Another function of qualitative research is evaluative – appraising the effectiveness of current programs, processes, institutions, etc. (Merriam, 2003b; Patton, 2002; Ritchie, 2003). Such an approach generates detail-rich data and in-depth observations. It renders itself effective in looking at the whole program as well as its units (Patton). The current study aims to evaluate teacher education participant understanding regarding several target aspects of NOS in the final year of a 4-year undergraduate teacher education program. Differences between preservice teachers understanding of aspects of NOS across teacher education program characteristics were evaluated and compared. The intent was to understand the differences between the participating preservice teacher understanding aspects of NOS and identify patterns and themes related to those understandings, participant characteristics, and other program features which may be linked to any detected similarities or differences. Such aims are consistent with the evaluative and descriptive focus of qualitative research identified by Maykut and Morehouse (1994) and Lewis (2003). In addition to its evaluative and descriptive function, the design resulted in data from interviews and document analyses, used inductive data analysis, and considered the researcher as the primary instrument for data collection and analyses – all necessary features of good qualitative research (Maykut & Morehouse; Merriam, 2003a; Patton; Ritchie; Snape & Spencer, 2003). The design may be considered naturalistic inquiry as program activities or components were not manipulated nor examined for cause and effect relationships (Newman & Benz, 1998). Rather the study is ex-post facto in nature and unobtrusive.

The research question "What variables or factors discriminate between the different levels of understanding aspects of NOS among the teacher education program participants?" is answered using associational research – an approach that investigates relationships using correlation and causal-comparative methodologies (Fraenkel & Wallen, 2003; Newman & Newman, 1994). Correlational research is descriptive in nature as it describes the degree to which two or more variables are related and it examines those relationships without trying to influence or manipulate the variables themselves. It is appropriate to use correlational methods when participants (a) have not been randomly assigned to a group or to a treatment but rather self selected as a group to a particular level of an independent variable and (b) participants are in a single group and it is the relationships among multiple variables within that single group that are being examined (Fraenkel & Wallen; McCracken, 1991; Warmbrod & Miller, 1974). In this investigation, participants self selected the teacher education program and the various facets or characteristics within the program. Identifying and describing such relationships is useful with regards to informing faculty of which program characteristics should be considered for further evaluation when assessing program effectiveness in developing preservice teacher understanding aspects of NOS (Newman & Benz, 1998).

The Logic Model as an Organizational Framework

The Logic Model Process is used as a framework and incorporated into the research design to evaluate the function of a teacher education program regarding participant understanding aspects of NOS. Specifically the Logic Model Process examines connections or linkages between initial conditions to be addressed, characteristics of participants prior to participation in the program, program activities or transactions that address the conditions, and the outcomes of the program both short term and long term (Cooksy et al., 2001; Julian, 1997; Renger & Hurley, 2006). The strength of the Logic Model is its ability to consider the connections or linkages between the antecedents, the activities used to address the conditions, and the expected outcomes (Julian; Julian, Jones, & Deyo 1995; Renger & Hurley). The model is an integrative framework used to focus data collection, organize the data, and interpret the data. It is meant to be descriptive, portraying the logical and sequential order from inputs to outcomes and permits the researcher to examine the extent to which the program accomplishes its stated outcomes (Julian; Patton, 2002). In this sense, the Logic Model is an integrative framework for a normative evaluation comparing the espoused theory of what the teacher education should accomplish to what is actually accomplished using the data as generated from the program in order to uncover any inconsistencies (Cooksy et al.; Patton). Such an examination is only possible when the model has been described in realistic terms and qualitative inquiry is especially appropriate for achieving that description (Patton). However, a limitation of the Logic Model Process is that it is not intended to establish cause and effect relationships between the activities and the outcomes of the individual programs. Rather the Logic Model evaluates whether those who have participated in the program have attained the target or desired outcomes upon completion of the program (Cooksy et al.; Julian; Julian et al.). Patterns or themes regarding program activities or features and outcomes may be observed and further scrutinized but, given the constraints of the complexities and dynamic nature of the program environment and the complex nature of learning, it cannot be utilized to establish measurable cause and effect relationships (Julian; Julian et al.). The research design is organized within the framework of a Logic Model Process to evaluate the teacher education program's effectiveness in preparing preservice teachers' with an informed understanding of NOS aspects (See Table 3.1.).

Antecedents	Transactions	Outcomes	Impacts
Participant characteristics	Teacher Education Program features	Informed views on target aspects of NOS	Effective science teacher in the classroom

Table 3.1. The Logic Model Process for a teacher education program with regard to aspects of NOS.

The antecedents in the first column of Table 3.1 are characteristics or descriptions of participants entering year 1 of the 4-year teacher education program. These characteristics are descriptive of participant performance and background in high school that may serve as indicators of their potential development of understanding aspects of NOS. The literature review supports the assumption that preservice teachers generally hold misconceptions related to one or more of these aspects and their understanding of NOS is often categorized as uninformed. If the actual understanding of aspects of NOS among the participants in year 1 is known, they could be considered the initial conditions or antecedents in the model. Since these are not known, the decision was made to use characteristics such as college entrance scores, high school cumulative grade-point averages, etc. and consider them as participant antecedents. Such characteristics are used in the university admissions process as indicators of potential success and cognitive development in the university setting. Hence, they may indicate the potential for developing an informed understanding of the target aspects of NOS.

The Transactions: teacher education program, the second column, has embedded in it variables or transactions including education courses, science courses, methods courses, etc. that are intended to produce various immediate outcomes, the third column. In this study the immediate outcomes examined were participant understanding of the seven target aspects of NOS. These immediate outcomes of understanding aspects of NOS are considered necessary (Lederman, 1992b) if effective science teaching, the impacts, (the fourth column) are to be realized. The transactions column was later separated into two sub groups – transaction experiences such as enrolled in various courses and transaction performances or outcomes related to these experiences, e.g., grades in these courses – for consistent use of the terms transaction and outcomes (see Table 3.3).

The target aspects of NOS examined in this study are drawn from the literature review and are often examined in NOS studies related to K-12 students and preservice teachers (Abd-El-Khalick, 2001; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2007; Hanuscin et al., 2006; Lederman et al., 2001; Schwartz et al., 2004). Table 3. 2 identifies the target aspects of NOS addressed in column three of Table 3.1. The long-term outcomes or impacts are beyond the purview of this investigation and will not be addressed.

Outcomes: Informed views on the following aspects of NOS.	Abbreviations
Empirical nature of scientific knowledge	EMP
Inferential nature of scientific knowledge	INF
Theory-laden nature of scientific knowledge	THL
Distinction between a scientific law and theory	DLT
Social and cultural nature of scientific knowledge	SOC
Tentative nature of scientific knowledge	TEN
Creative and imaginative nature of scientific knowledge	CRI

Table 3.2. Outcomes: Target aspects of NOS.

Participants and Context of the Study

Participants for the study were members of the undergraduate teacher education program of a private, religious-affiliated Midwestern university. The university is situated in a rural, small town community and offers undergraduate arts, sciences, and professional programs and graduate education programs. Generally enrollment in the undergraduate programs is approximately 3,000 students and 100 students in graduate school programs. Teacher education participants were selected for recruitment into the study if they met the following criteria: (a) enrolled as either Early Childhood (EC), Middle Childhood – science concentration (MC-S), or Adolescent/Young Adult-science education (AYA-S) majors and (b) in year 4 of a traditional 4-year program. Participants in these majors were expected to teach various aspects of NOS as prescribed by the accrediting and license granting state and are the population of interest. All participants self-selected membership into the teacher education program as well as their major. Thirty-five year 4 participants volunteered to participate in the study. The total number of year 4 students at the time of the first data collection was 47. Three students were out of the country completing their student teaching internship and 6 students did not attend the scheduled seminar during which the data were collected. Three students were recruited into the study the following academic year, as year 4 members, to provide increased representation for some of the variables within the teacher education program (i.e. gender, program major). The number of students in the study was 38. The student population was approximately 95% percent Caucasian and 84% female with most males (4), enrolled as AYA Science Education majors. See Table 4.1 for additional descriptions of student participants in the study.

As students in the teacher education program, participants had to meet program entrance requirements and continuing enrollment requirements in order to successfully complete the program and receive a diploma and teaching licensure. Requirements pertain to all participants whether EC, MC-S, or AYA-S program majors and include meeting the following criteria: (a) minimum cumulative 2.7 GPA on all course work (based on a 4.0 grading scale), (b) minimum cumulative 2.7 GPA in teacher education program core curriculum courses, (c) all teacher education program curriculum core courses completed with a grade of "C-" or above, (d) minimum cumulative 2.5 GPA in teaching field content area(s), (e) all teaching field or concentration area courses completed with a grade of "C-" or above, (f) overall GPA of 2.65 and a grade of C- or above in both general education communication courses: Fundamentals of Speech and English Composition, (g) minimum passing scores on the state-required Praxis I exam (waivers may be granted based on ACT/SAT scores and performance in selected course work), (h) passing scores on state-required Praxis II exams prior to student teaching, (i) a "C-" or above in all methods courses, and finally (j) recommended to the teacher education program by the education department's admission interview committee. All participants were in good standing at the time of data collection and since have successfully completed their major program, met state licensure requirements, and are qualified to teach in the appropriate K-12 grade level classroom.

Instrument

Studies using standardized assessments have most often used assessments with closed-ended questions which assume that respondents perceive and interpret items in a manner similar to the instrument's developer(s). Follow-up procedures to ensure the validity of the instrument were not conducted for each administration of the assessment. It was assumed by those studies that the validity established initially in the development of the instrument would be applicable in all situations to all participants. Given the variance of demographics within and between localities, regions, and states such an assumption is viewed as problematic in an attempt to elucidate student understanding of

NOS (Lederman et al., 2002). Closed-ended questions such as multiple choice or forced choice allow the respondent to select his or her answer from a number of options. However, they do pose the possibility that an individual's true response is not present among the choices (Fraenkel & Wallen, 2003; Lederman, Wade, & Bell, 1998). Lederman and his colleagues described such a situation as respondents picking choices that are imposed upon them and then labeled in categories based upon those imposed choices (Lederman et al., 2002). To avoid this imposition of forced choices upon participant responses, an open-ended instrument was chosen.

The instrument used to survey preservice teacher understanding aspects of NOS was the Views of Nature of Science Questionnaire (VNOS). The Views of Nature of Science Questionnaire has several versions, all of which use open-ended questions. The most frequently used versions are the VNOS–B (7 items) and the VNOS–C (10 items). Both questionnaires give participants the freedom to express their understandings of the seven target aspects of NOS in their own words. The instruments are used to elucidate and clarify respondents' understanding of aspects of NOS and not to necessarily categorize those understandings for summative purposes as the aim of the study was descriptive and associational. The VNOS-C version was chosen for this study since it is a modification and expansion of the VNOS-B. In addition to prompting responses to views of NOS targeted by VNOS-B, the VNOS-C aims to assess views of the social and cultural nature of science and provides additional prompts for other target aspects. The aspects of NOS addressed by the VNOS-C include each of the target aspects identified in Table 3.2. The VNOS-C questionnaire and the alignment of the questions to target NOS aspects is found in Appendix A and is based on the work of Lederman et al. (2002), and

Kim (2007). By its nature, the instrument does not assume a restrictive one-to-one correspondence between a specific questionnaire item and an express aspect of NOS (Lederman et al., 2002). Reponses to questionnaire items could be and were used to describe more than one target aspect of NOS.

Instrument Validity

Reponses to opened-ended questions are harder to score and more difficult to interpret than forced-choice questions. However, the use of the semi-structured interview addresses these issues as respondents are asked to explain their responses, clarify meanings they ascribe to key terms, and provide examples (Lederman et al., 2002). The VNOS–B questionnaire is a revision of the original VNOS form and uses a semi-structured interview to establish internal validity (Abd-El-Khalick et al., 1998; Lederman et al, 2002). The VNOS-B was tested for construct validity as the researchers administered the VNOS–B to two groups of 9 participants each: a novice group and an expert group. After the interviews, researchers discovered clear differences in the expert vs. novice responses regarding NOS. The instrument was further modified and expanded to the VNOS–C questionnaire. A panel of five experts examined the items for content validity and the items were modified accordingly. Profile comparisons indicated that interpretations of participants' views as elucidated on the VNOS–C questionnaire were congruent to those expressed by participants during individual interviews. Several studies used the questionnaire and semi-structured interview follow-up protocol and further established the validity of the VNOS-C (Abd-El-Khalick, 2001; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000b; Akerson et al., 2007; Bell & Lederman, 2003; Hanuscin et al., 2006; Lederman et al., 2001; Schwartz et al, 2004).

Validity of the VNOS-C questionnaire was affirmed in this study by interviewing 19 (50%) of the participants using the recommended semi-structured interview follow-up protocol (see Appendix B). Interview responses were compared to written responses to the VNOS-C questionnaire for consistency. Inconsistencies between participant interview and questionnaire responses were few and minor – they were not sufficient enough to alter the researcher's interpretation of the responses. In several cases researcher interpretations of written responses were modified based on clarification and elucidation during the interview. Priority was given to interview data when inconsistencies did exist between questionnaire and interview data (Lederman et al., 2002). The VNOS-C questionnaire was made available with permission from the authors.

Data Collection

The VNOS–C was administered to participants during a scheduled student teaching seminar toward the end of their student teaching experience and final semester of the program. Participants who volunteered for the study were given the opportunity to leave at anytime during the administration without incurring any penalty. The questionnaire was given under controlled conditions with participants given adequate time (1 hour) for responding. Each item from the VNOS-C questionnaire was printed on a separate page to give respondents ample space to fully reply. Participants were informed that there were no right or wrong answers and were encouraged to write as much as they could, addressing all subsections, and providing examples when asked. Participant responses were then transcribed.

Follow-up interviews were conducted with 19 selected individuals using a semi-structured protocol (see Appendix B). This represented 50% of the participants, exceeding the suggested 33% representation advised by the VNOS-C developers to establish validity within the context of the study (Lederman et al., 2002). Interviews were conducted in controlled settings and often lasted 35- 40 minutes. Responses to the interview questions were recorded (with the permission of the participants) and transcribed. Selection of participants for interviewing was ascertained by membership related to a variable of interest in the study, the declared program major. Teacher education participants were enrolled as EC, MC-S, or AYA-S program majors. The majority of participants were enrolled as EC majors (66%) and 7 of the 25 EC majors were randomly selected for follow-up interviews. Only 7 (18%) of the participants were MC-S majors and 6 (16%) were AYA-S majors. Six of the 7 MC-S majors were interviewed along with each of the 6 AYA-S major participants. See Table 3.3.

	Participants		Interviewed	
Program Major	No.	%	No.	%
EC	25	66	7	18
MC-S	7	18	6	16
AYA-S	6	16	6	16
Total	38	100	19	50

Note. EC = Early Childhood, MC-S = Middle Childhood-science concentration, and AYA-S = Adolescent/Young Adult science education.

Table 3.3. Number of participants surveyed and interviewed by program major.

The intent was to numerically distribute the interviews evenly among the majors in the event of changing the research design to a case study, treating each major as a case. Questionnaire responses and interview transcripts were compiled based upon participant's understanding of the chosen aspects of NOS in the study.

Several different records related to the participants were collected for content analysis. Hodder (2000), using Lincoln and Guba's criteria, distinguishes documents as prepared or written for personal reasons (e.g., diaries, letters, and field notes) from records which testify to some formal dealings (e.g., birth certificates and standardized test results). Records of participant characteristics examined were high school and college transcripts, planning guides for the different teacher education program majors, and syllabi from required science teaching methods courses and science content courses. The records provided the pool of participant characteristics for consideration as antecedent and transaction predictor variables related to the NOS outcome variables.

Course syllabi were examined to determine which, if any, courses explicitly stated aspects of NOS as course objectives or assessment items. Such explicitly stated objectives would give indication that participants were intentionally taught and assessed on aspects of NOS. Follow-up interviews or communications were carried out with instructors of these courses to corroborate that any aspects of NOS explicitly stated as course objectives were indeed taught and assessed during these courses (Silverman, 2000). Planning guides for the various majors within the teacher education program were examined to identify and understand the context of participant responses and understanding aspects of NOS. Analysis of the program planning guides also sought to identify additional variables for consideration in examining relationships between participant characteristics and understanding aspects of NOS. Participant college and high school transcripts were examined to determine a list of variables for this study. Specifically the transcript records were viewed as giving some indication and evidence of participant capabilities and/or performance in the teacher education program though caution was exercised in considering them as absolute or hard evidence of what they report (Atkinson & Coffey, 1997).

Using the Logic Model Process as a framework, participant characteristics were classified as antecedent or transaction predictor variables. The Logic Model Process as described in Table 3.1 was modified to separate transaction experiences from performances or immediate outcomes related to those experiences. Table 3.4 lists and classifies participant characteristics based on the Logic Model Process and includes this modification. Praxis II Subject Assessments and Principles of Learning and Teaching Test results were given consideration as possible transaction predictor variables. However they represent outcomes of the teacher education program and do not directly assess any of the target aspects of NOS. Hence they were not included as transaction variables in the Logic Model Process evaluation.

Antecedents: Participant Characteristics	Teacher Education Program Transactions		Outcomes: Informed views on target aspects of NOS
	Experience	Outcomes	
Type of High School attended	Program (major, grade-level licensure)	Cumulative university GPA	Empirical nature of scientific knowledge
High School GPA	Total science credit hours	Cumulative science courses GPA	Inferential nature of scientific knowledge
High School GPA-science courses	Principles of Earth Science	Principles of Earth Science grade	Theory-laden nature of scientific knowledge
Total High School science credits	Physical Science for Teachers	Physical Science for Teachers grade	Distinction between a scientific law and theory
Type of science course credits	Principles of Biology	Principles of Biology grade	Social and cultural nature of scientific knowledge
ACT Composite score	Special Education Endorsement Program.	Cumulative education program GPA	Tentative nature of scientific knowledge
ACT Science Reasoning score	Middle Childhood - math concentration		Creative and imaginative nature of scientific knowledge
ACT Math score			
SAT Combined score			

Note. GPA is the grade-point average based on a 4.00 scale.

Table 3.4. Classification of predictor variables using the Logic Model Process.

Of the transaction experiences listed, three were courses required for the majority of participants. The Principles of Earth Science course is a survey of geology, oceanography, and meteorology designed for non-science majors. Topics include geological history of the earth, plate tectonics, ocean currents, weather systems, among others. The Principles of Earth Science course is required for all teacher education program participants and fulfills a general education requirement. Physical Science for Teachers introduces core concepts of chemistry and physics to participants who are in the EC and MC-S program majors. This course emphasizes the pedagogy of students learning science along with science content. Basic life processes, and the principles by which they operate at the ecological, organismic, and cellular levels are introduced to students in the Principles of Biology course. The course also introduces NOS aspects to students within the context of biology. This is a required course for all participants in the teacher education program with the exception of AYA Life Science program majors.

Some participants did not have data for one or more variables listed in Table 3.4 which presented a problem in the statistical treatment of the data. A missing-data issue concerned scores for the American College Test (ACT) and the SAT Reasoning Test. Most participants (*n*=29, 76%) submitted ACT scores to fulfill the university's admission requirements with the remainder (*n*=9, 24%) only submitting the SAT Reasoning Test scores. The ACT and SAT Reasoning Tests are different tests and do measure similar but distinct constructs (ACT, 2008). As stated by ACT (2010b):

> The ACT tests are curriculum-based tests of educational development. Their content is intended to be representative of knowledge and higher-order thinking skills that are explicitly taught in typical college-preparatory programs and that are essential for success in college. The ACT measures academic achievement in the areas of English, mathematics, reading, and science. The SAT, in contrast, measures reading, writing, and mathematical reasoning, and is less closely linked to high school and college curricula. Because the ACT and SAT are not parallel in content, and different students have different strengths and weaknesses, there is really no such thing as an "equivalent" score on the two tests. (para. 1)

The decision was made to use ACT scores, including Composite, Natural Science, and Mathematics, as variables of interest in the study since they were more closely related to participant development of the stated outcome of understanding aspects of NOS in the study. Also, fewer data points would have to be generated using the ACT scores as opposed to SAT Reasoning Test scores. Participants who only had SAT reasoning test scores had those scores converted into ACT composite concordant scores using the published ACT – SAT Concordance table (ACT, 2008;). It must be noted that while the concordance table does not equate scores, it is a tool for finding comparable scores. ACT, (2010b) explains that:

> Concordant scores are defined as those having the same percentile rank with respect to the group of students used in the study. The tables are useful for determining the cutoff score on one test that results in approximately the same *proportion* of students selected by the other test (although not necessarily the same *students*). The table shows, for example, that an ACT Composite score of 20 has a concordant SAT CR+M score of 950; these scores would typically result in selecting approximately the same proportion of students. Use of the concordance tables to estimate *individual* student performance will provide comparable scores that are less accurate than would estimates based on other statistical procedures. (para. 3)

Since other data and statistical procedures were not available for this study, the concordance scores were used to estimate individual student performance and the accuracy of those scores is a limitation to be considered

The missing data for participants' ACT Science Reasoning scores (ACTS) and ACT Mathematics scores (ACTM) had to be derived using the ACT concordant score. Starting with the assumption that the relationship is linear between the variables ACTS and ACT Composite scores (ACTC) as well as linear between ACTM and ACTC (ACTC is the independent variable in both cases and ACTS and ACTM are dependent), a least square regression was fitted between each set of variables. For ACTS ~ ACTC, ACTS = 3.35 + 0.83*ACTC with r^2 of .83 where 3.35 is the value of ACTS when ACTC is equal to 0 for the fitted line (Y-intercept for the line) and 0.83 is the rate at which ACTS changes for one unit change in ACTC. For ACTM ~ ACTC, ACTM= 1.46+0.91*ACTC with r^2 = .78 where 1.46 is the value of ACTM when ACTC is equal to 0 for the fitted line and 0.91 is the rate at which ACTM changes for one unit change in ACTC. Using these two relationships, ACTS and ACTM scores were calculated for participants who did not submit ACT scores as part of their university admissions process. Such contrived means of filling in missing data is not ideal and does inflate the degrees of freedom in statistical procedures. However these limitations outweigh the difficulties of completing statistical analysis with missing data.

Another missing-data issue involved the variable of the Principles of Biology (GBIO 1000) grade; the grade earned in the biology course for non-biology majors. This course meets the general education requirements for students in the EC and MC-S majors but it is also a course which satisfies science credit requirements for the accrediting agency of the university's teacher education program. Students may meet this requirement by transfer credits or by passing the College Level Examination Program (CLEP) Biology Examination. In both of these cases, only credit is given for the class. Grades are neither posted to students' transcripts nor calculated into their grade-point averages. Eight of the 38 participants either transferred in the Principles of Biology (GBIO1000) credit or received credit for passing the CLEP Biology Examination. To ameliorate the problem of missing data the mean Principles of Biology grade-point average was calculated for each education major in the teacher education program (EC, MC-S, and AYA-S) and that mean was assigned to the participants in that major who were missing the data.

Four participants in the AYA Life Science Education program major completed the Introduction to Biology course, a required course for the major for which credit is given towards the general education requirement in place of Principles of Biology

(GBIO 1000). Grades from the Introduction to Biology course were used as data for these participants as analysis of the course syllabi indicated an 80% agreement between the Principles of Biology course and the Introduction to Biology in topics covered, though in greater detail and with more rigor in the Introduction to Biology course. A similar situation presented itself for participants completing the Physical Science for Teachers and the Principles of Earth Science courses and the grade earned in each. The Physical Science for Teachers course is required for EC program majors and MC-S program majors. Both situations were ameliorated in similar fashion to the Principles of Biology issue by using mean grade-point averages.

Aligning Participant Responses to Aspects of NOS

Participant responses to the VNOS-C questionnaire were transcribed along with recorded interviews with selected participants. Interviews were semi-structured and in general followed the order of the VNOS-C items. Transcribed responses were identified according to the generated source, i.e., VNOS-C question number or interview (See Table 3.5). Two readings for each participant's responses were undertaken to align responses to items in the VNOS-C items with the target aspects of NOS using the alignment table in Appendix C as a guide. Responses to questionnaire items were interpreted as describing more than one target aspect of NOS (Lederman et al., 2002), and where appropriate for use as evidence for understanding other aspects of NOS. The analysis for alignment continued as a secondary emphasis when participant responses were categorized as to level of understanding for target aspects of NOS. Thus, several iterations of aligning responses to appropriate aspects of NOS occurred during data analysis.

Tentative Aspect of NOS	
Participant	Evidence
10	Theories are not known to always be true and are sometimes revised, rejected or reassembled. … are subject to change when new evidence is found that supports a new theory or requires modification to the old. ***VNOS-C 4*** Bohr's model of the atom is no longer accepted as the correct model. This model fails to explain bonding theories. Scientists are not sure of the exact structure of the atom. The currently taught model is the quantum mechanical model – based on Schrodinger's mathematical calculations of a probability cloud for the location of electrons, Rutherford's gold foil experiment and the cathode ray tube experiment. ***VNOS-C 6*** - Um--yes. I'm trying to think of an example. I mean like you can revisit old data based on new assumptions and interpret that differently. ***Interview*** - Hmmm. I'm struggling for examples. Um--I think yes they [laws] can change. Can I leave that with an I don't know? ***Interview***

Table 3.5. Example of a participant's responses aligned to the tentative aspect of NOS.

Categorizing VNOS-C and Interview Responses

Consistent with features of qualitative research, the general approach to the analysis of participant responses to the VNOS-C was inductive as described by Patton (2002) and Bogdan and Biklen(1998). A scheme for categorizing participant responses to the VNOS-C and interviews was developed using Stella Vosniadou's view of conceptual change in the learner (Vosniadou, 1999, 2002, 2003; Vosniadou et al., 2001, 2004) and scoring rubrics or strategies from several studies which used the VNOS-B or VNOS-C instrument (Akerson et al., 2007; Hanuscin et al., 2006; Schwartz et al., 2004; Seker, 2004). A summary of the classification schemes from several studies is presented in Table 3.6.

Akerson et al. (2007)	Schwartz et al. (2004)	Hanuscin et al. (2006)	Seker (2004)	Vosniadou (1999)	Current Study (2010)
No understanding	(-) Inconsistent or inappropriate descriptions or examples	(-) Contradictory to reform characterizations	Naïve	Naïve	Uninformed
Emerging - Some understanding with persistent misconceptions			Intermediate	Synthetic	Syncretic
Informed - No contradictory answers present in instrument response	(+) Provides definition or affirmative response	(√) Aligned with reform characterizations	Informed	Scientific	Informed
	(++) Description in words of the participant	(+) Enriched view			
	(+++) Description in words of the participant with examples				

Table 3.6. Comparison of studies categorizing understanding aspects of NOS.

Using these sources, three categories of scores were proposed for use in this study: uninformed, syncretic, and informed to correspond to Vosniadou’s (1999, 2002, 2003) naïve, synthetic, and scientific categories respectively. The terms uninformed and informed were chosen as category titles as they are described and frequently used in the literature (Abd-El-Khalick, 2001; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000b; Bell, Binns, Schnittka, & Toti, 2006; Lederman et al., 2001; Schwartz et al., 2004). Studies listed in Table 3.6 also provided descriptions of uninformed and informed understanding of the target aspects of NOS. Some expanded the categorizing of their subjects' views of aspects of NOS beyond uninformed and informed. Akerson et al. (2007) used an "emerging" category to describe those subjects who have some understanding of aspects of NOS though misconceptions persist in their understanding. Two studies – Hanuscin et al. (2006) and Schwartz et al. (2004) – used several categories but they did not necessarily correspond to the categories used by Akerson et al. Both Hanuscin et al. and Schwartz et al. started with uninformed views but included inconsistencies and contradictory statements in this category as opposed to creating an "emerging" category. The "++" and "+++" descriptive categories (see Table 3.6) used by Schwartz et al. were differentiated from the "+" category by (a) going beyond simple affirmations or definitions of the aspects and (b) the use of appropriate examples, respectively. Hanuscin et al. distinguished the "(√) aligned" category from the "(+) enriched" category by the richness of the stated understanding. Such inconsistencies between the descriptions of scoring categories of the examined studies were not helpful in developing the criteria for scoring categories used in the rubrics for this study.

Syncretic was chosen as the descriptive term for the scoring category to represent the transition of participant understanding from uninformed to informed. The term is often used in reference to religious or philosophical belief systems which are a combination of different, and at times contradictory, beliefs or practices. Syncretic is more descriptive than Vosniadou's category of synthetic view. It includes more than participants reconciling their understanding of what science is as presented in the classroom with their personal theories of epistemology. Syncretic describes the participant holding on to different beliefs, views, and understandings of science simultaneously and at times holding some in abeyance depending on context.

Four iterations of reading and classifying participant responses to the VNOS-C questionnaire were completed for each target aspect of NOS. During this process, a fourth category of classification emerged for five of the seven target aspects. In each of these cases, it was observed that some participant responses categorized as syncretic were disparate enough from other participant syncretic responses as to indicate a notable difference between them and to consider revising the scoring rubric for these specific aspects of NOS. It was decided by the researcher, where the data supported the view, to create a fourth category. The additional category was labeled syncretic (+) to indicate that the understanding of the target aspect of NOS may be closer to an informed understanding and more elaborate and rich in describing the target aspect. Responses categorized as synthetic (+) had fewer inconsistencies or misconceptions than other responses categorized as syncretic which conformed more to an uninformed understanding. These "less informed" syncretic understandings were categorized as syncretic (–). The rubrics used to categorize participant responses as informed, syncretic (+), syncretic (-), and uninformed for each target aspect of NOS are listed in Appendix C. For the purpose of statistical treatment a scoring scheme was devised to represent the classification of participant responses. The scoring scheme was based on a 4- point scale with 0 = uninformed, 1 = syncretic (-), 2 = syncretic (+) and 3 = informed understanding. Examples of participant responses categorized and scored for each target aspect of NOS are found in Appendix D. Participant responses were scored for the individual target aspects of NOS. Composite scores for each participant based on the participant's responses for all 7 target aspects of NOS was not determined.

Analysis of the target aspects of *tentativeness* (TEN) and the use of *creativity and imagination* (CRI) did not present data that warranted a further delineation of the syncretic view and thus the initial three categories of understanding were retained. However, the scale for these two categories, TEN and CRI, were adjusted to the same 3-point scale to maintain the consistency of scoring the understanding of target aspects of NOS. A score of "0" continued to represent an uninformed understanding while an informed understanding was scored a 3 and syncretic was scored as 1.5. The final scoring rubric used for the target aspect of NOS is listed in Appendix C. Examples of categorized and scored participant responses for each of the target aspects of NOS are listed in Appendix D.

Statistical Treatment

Correlational analyses. The collected data from participants' high school and college transcripts along with the scored responses from the VNOS-C questionnaire and interviews were examined to determine if any relationships existed among the participant characteristics and their understanding of aspects of NOS. Using R software (R Development Core Team, 2010) an exploratory analysis was conducted to determine correlation coefficients for pair-wise models of all participant characteristics compared to one another and the scored aspects of NOS understanding. The analysis calculated the Pearson Product Moment Correlation Coefficient (r) to indicate the strength of the linear relationship between paired variables. The determination of Pearson's r is a tool which permits the researcher to investigate the extent to which one or more relationships exist between the variables under study (Fraenkel & Wallen, 2003; Newman & Newman, 1994). Participant characteristics identified as antecedents and transactions using the Logic Process Model as the design framework (see Table 3.4) were treated as predicator variables and the understanding aspects of NOS as outcomes or criterion variables for multiple regression analysis (Fraenkel & Wallen).

Faraway (2002), Fraenkel and Wallen (2003), and Newman and Newman (1994) identified the accepted minimum correlation values for variables in social science research as $r \geq 0.40$. Values of $r \leq 0.35$ indicate at best a slight relationship and have little or no value in a predictive sense (Fraenkel & Wallen). The decision was made by the researcher to choose predictor variables for further examination which had correlations statistically significant ($r \geq 0.41$ at $\alpha = 0.01$) with NOS outcomes. The lower α level of $\alpha = 0.01$ was set, deviating from the norm of $\alpha = 0.05$, to make a more rigorous test in determining if relationships existed between the predictor variables and NOS outcome criterion variables. A two-tailed test was used instead of a one-tail test to determine significance. The lack of support from the reviewed literature to predict any relationship between the predictor and NOS outcome variables coupled with the exploratory nature of the study obligated the researcher to use a two-tailed test to determine statistical significance (Fraenkel & Wallen; Newman & Newman).

Correlation coefficients were calculated between the 7 NOS outcome variables to examine to what extent participant understanding of one aspect of NOS was related to their understanding of other target aspects of NOS. Studies suggest that a person's understanding of one aspect of NOS is related to his/her understanding of other aspects of

NOS (Lederman et al., 2002). An attempt to confirm this view was undertaken in this study as a tangential objective.

Multiple regression analyses. Fourteen of the 27 predictor variables were significantly correlated ($r \geq 0.41$ at $\alpha = 0.01$) to at least one NOS outcomes variable (see Tables 4.4 and 4.5) and were selected for use in multiple linear regression analyses. Predictor variables which were not significantly correlated with at least one of the 7 NOS outcome criterion variables were excluded from further examination. Other predictor variables significantly correlated to the 7 NOS outcomes were excluded for reasons discussed in proceeding sections. This was done in accordance with Kerlinger and Pedhazur's (1973) view, that ideally, multiple regressions should use predictor variables that have high correlations with the criterion variables. Kerlinger and Pedhazur argue against the indiscriminate us of variables or the "shotgun approach" (p. 442) in regression analyses. Rather they suggest using some method of analysis to reduce the number of variables entered into the analysis. Fewer variables in a multiple regression analysis provide a more persuasive and compelling model to account for variance in the criterion variable of interest. Additionally, removing predictor variables not significantly correlated to the criterion variables keeps the degrees of freedom from unnecessarily being reduced which may result in decreased usefulness in explaining and predicting the criterion variables (Faraway, 2002; Kerlinger & Pedhazur).

Other predictor variables were moderately correlated to a criterion variable but were not chosen for regression analysis due to other considerations. For example, gender was moderately correlated with the empirical aspect of NOS ($r = 0.46$) and the distinction between law and theory ($r = 0.41$). However, gender is closely associated with another variable, the teacher education program major. Participants in the EC (96%) and MC-S (86%) program majors were predominately female. Keeping gender as a characteristic for regression analysis could possibly dampen the real effect that participant program major has on NOS outcome criterion variables and place undue emphasis on gender which is not warranted by the literature. Table 3.7 identifies and categorizes the selected participant characteristics as antecedent or transaction predictor variables within the framework of the Logic Model Process.

The selection of some variables and the exclusion of others for regression analysis address the problem that the prediction power of best-fit models generated by regression analysis is decreased by the addition of variables (Kerlinger & Pedhazur, 1973). To increase predictive power and achieve parsimony, the smallest model in terms of the number of predictor variables is highly valued (Faraway, 2002). The relative effectiveness of the predictor variables used in regression analysis is affected by the order of the predicator variables entered into the equation. A predictor variable may act differently if added as a second variable rather than the first (Kerlinger & Pedhazur). The Logic Model Process categorizes predictor variables on the basis of a temporal relationship into antecedents and transactions (see Table 3.7). The temporal relationship between predictor variables dictates to some measure the order they enter the multiple regression analysis equations and removes some ambiguity regarding the interpretation of the analysis. The significance of a predictor variable (*p* value) may change in the regression analysis based on order but the order of entering the predicator variables does not alter the value of the multiple correlation coefficient of determination (R^2), (Kerlinger & Pedhazur).

Antecedents: Participant Characteristics	Teacher Education Program Transactions		Outcomes: Informed Views of Target Aspects of NOS
	Experience	Outcomes	
ACT Composite Score (ACTC)	Program (PROG)	Cumulative university GPA[a] (CGPA)	Empirical (EMP)
ACT Science Reasoning Score (ACTS)		Education program GPA[a] (EGPA)	Inferential (INF)
ACT Math Score (ACTM)		Science courses GPA[a] (SGPA)	Tentative (TEN)
High school GPA[a] (HSGPAC)		Total science credit hours (SCICH)	Theory-laden (THL)
High school science GPA[a] (HSGPAS)		Principles of Biology grade (GBIOG)	Creative & imaginative (CRI)
High school science credits (HSSCI)		Principles of Earth Science grade (ESCIG)	Social & cultural (SOC)
		Physical Science for Teachers grade (PSTG)	Distinction between scientific laws & theories (DLT)

Note. [a] GPA is the grade-point average based on a 4.00 scale. Abbreviations for each characteristic are listed and used in tables displaying results.

Table 3.7. Classification of selected predictor variables using the Logic Model Process.

Antecedent predictor variables were entered as one set of predictor variables and compared to NOS outcome criterion variables in a full model regression analysis. Transaction predictor variables were entered separately as a second set into a full model regression analysis with the same NOS outcome criterion variables. The stepwise approach was used to determine the best-fit model with regards to R^2 for each set of predictor variables to the NOS outcome criterion variables. Best-fit models for both sets were chosen using the Akaike Information Criterion (AIC) criteria. The AIC is a test between models in a regression analysis to measure the goodness of fit of the model to the data. Using the AIC criteria gives the advantage of choosing models which best explain the data with a minimum number of variables, discourages over fitting of the model, and maintains parsimony (Burnham & Anderson, 2002; Faraway, 2002; Posada & Buckley, 2004).

The Logic Model Process framework suggests that variance in NOS outcomes cannot be attributed separately to antecedent variables or transaction variables and the amount of variance attributed to transactions in the teacher education program has to be determined with consideration of the temporal relationship between the antecedents and transactions. Participants bring into the teacher education program characteristics represented in part by measures of their high school experience, which are referred to in the Logic Model Process as antecedents. The transactions are measurements of those participant experiences in the teacher education program. Thus, the antecedent variables in the best-fit model for each of the target aspects of NOS were combined with the respective best-fit model transaction variables for the same target aspects of NOS.

A regression analysis was completed on the combined model to determine the amount of variance (R^2) attributed to the combined antecedent and transaction variables for each respective aspect of NOS. The amount of variance accounted for by antecedent variables for each NOS outcome is the R^2 value for each respective best-fit antecedent model. The variance attributed to transaction variables for each NOS outcome is the difference between R^2 values for the combined model and the antecedent best-fit model. Figure 3.1 represents this procedure to determine the variance attributed to antecedent variables and transaction variables for each target aspect of NOS. R^2_A is the coefficient of determination for variables 1 & 2 in the Best-fit model A for antecedent predictor variables. R^2_T is the coefficient of determination for variables 3 & 4 in the Best-fit model T for transaction predictor variables. R^2_C is the coefficient of determination for variables 1, 2, 3, and 4 in the full model for the combined variables model. X is amount of variance that cannot be attributed to any predictor variables in the three models. This determination is helpful in evaluating the success of the teacher education program to facilitate participant understanding of target aspects of NOS and which teacher education program transactions are related to development or impingement of those understandings

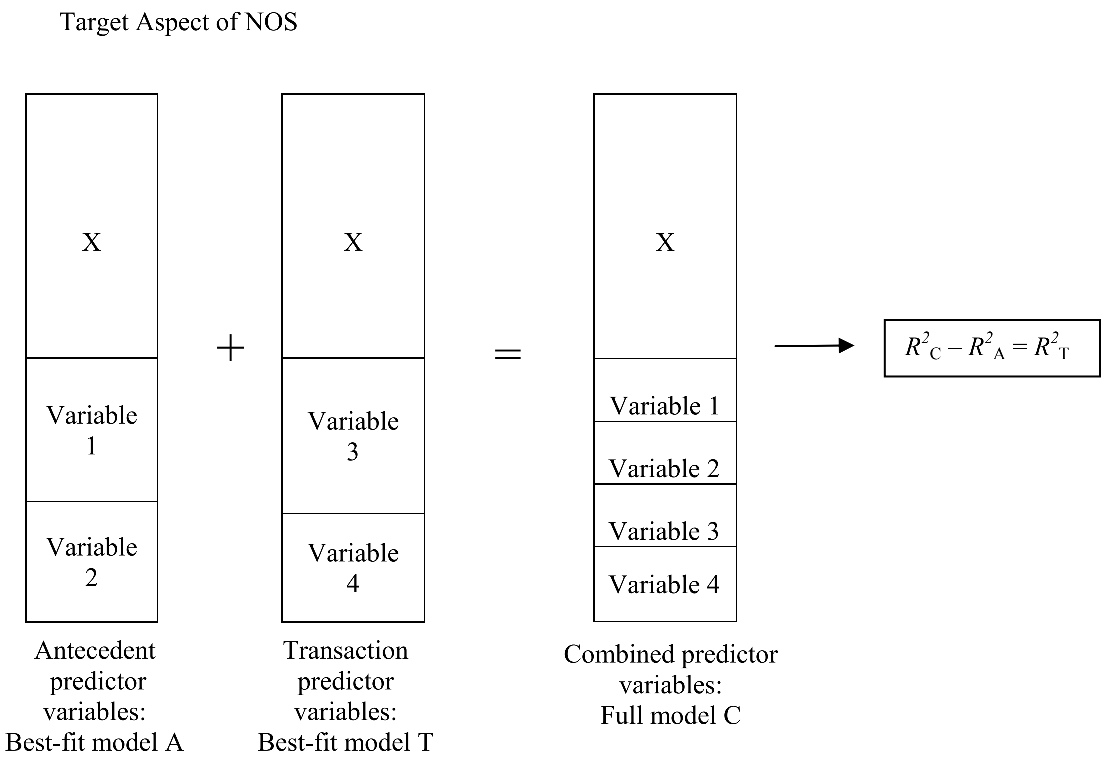

Figure 3.1. Conceptualization for determining the variance of NOS outcome prediction attributed to antecedent and transaction variables for each target aspect of NOS.

Limitations

Multiple regression analyses. Multiple regression analysis was chosen as a research tool for this study as it is suited to the analysis of non-experimental data with several independent variables (Kerlinger & Pedhazur, 1973). However there are several limitations inherent to the statistical treatment of the data using stepwise regression analysis as suggested by Faraway (2002), Kerlinger (1973), and Kerlinger and Pedhazur. First, the multiple significance testing occurring in the multiple regression analyses generates *p* values with some uncertainty as to their validity. Thus, it is important for the researcher to be cautious in stating the importance of the variables remaining in the best-fit model relating predictor variables to the NOS outcome criterion variables.

Second, predictor variables not selected for the best-fit models – either for the antecedent, transactions, or combined best-fit models – may still be related to the NOS outcome criterion variables. It is important to clarify that while the non-selected predictor variables may be correlated to the criterion variables and have some interaction with the selected predictor variables, no additional significant explanatory or predictive effect beyond the predictor variables was identified in the best-fit models. Third, the ideal best-fit model may not be identified due to the one-at-a-time addition or elimination of predictor variables during the regression analyses.

Fourth, the relative influence of the predictor variables is affected by the order of variables used in the multiple regression equations. Changing the order in which a predictor variable is added to the model may result in the predictor variable acting differently, changing its efficacy (Kerlinger & Pedhazur, 1973). By categorizing predictor variables as either antecedent or transaction, this potential threat is partly mollified. The Logic Model Process organizes the predictor variables into a temporal relationship and classifies these participant characteristics prior to admission into the teacher education program as antecedent. These antecedent predictor variables are entered into the regression analysis first and are then followed by the transaction predictor variables, those characteristics which are the result or are embedded in the TEP. Such an organization of predictor variables into antecedent and transaction variables acts as a constraint on the ordering of the predictor variables in the stepwise regression analyses.

The unreliability of regression weights (β) in the models is another potential limitation to the study. Small samples ($n \leq 40$) with several predictor variables are more likely to have greater standard errors and more fluctuations in beta weights compared to larger samples ($n \leq 100$) using fewer independent variables (Kerlinger & Pedhazur, 1973). With a sample of $n = 38$ for this study the threat of beta weight fluctuations is high. Kerlinger and Pedhazur suggest that for any regression analysis the reliability of the results and application to other contexts rests upon a large and representative sample and further replications of the study. Thus, this study can be replicated in subsequent years with year-4 participants in the teacher education program to gather data from additional representative participants to possibly reduce this limitation. Replicating the study with a different population may be another way to strengthen the reliability. Increasing the population increases the sample size to strengthen the reliability of the results and warrant the application of the study as an evaluative tool for the teacher education program. The threat of a large number of independent variables considered for regression analysis was lowered by selecting variables based on correlations with NOS outcome variables.Variables that did not have a moderate and statistically significant correlation to NOS outcome criterion variables were excluded from regression analyses. The unrelated variables are viewed as extraneous. The removal of such extraneous predictor variables which are not related to the NOS outcomes strengthens in some measure the internal validity of the findings between the selected predictor variables and NOS outcome criterion variables (Warmbrod & Miller, 1974).

Faraway (2002) and Kerlinger and Pedhazur (1973) cited the problem of high correlation among predictor variables causing multicollinearity which may be another weakness of the study. Several predictor variables selected for full model inclusion in the multiple linear regression were highly correlated, $r \geq 0.80$ (Fraenkel & Wallen, 2003). Examples of such high correlations between predictor variables include ACTC ~ ACTM: $r = 0.89$ and ACTC ~ ACTNS: $r = 0.92$. The variance inflation factor (VIF) was calculated for each set of predictor variables to check for multicollinearity. Only one predictor variable from a set of predictor variables demonstrating multicollinearity was entered into regression analysis on any one specific NOS outcome. Procedures to reduce this threat are described further in chapter 4.

Internal validity. Several limitations to internal validity are inherent to studies using an ex-post facto design with correlational methods. Participants are not randomly assigned to the teacher education program or different levels of the variables (e.g., type of program major) within the teacher education program. Rather, participants have purposely selected particular levels of some of the specified predictor variables (e.g., type of program/major). Hence, there is a confounding effect of self selection. Participants who selected the EC Teacher Education Program major may be different in characteristics as a group from those who choose the MC-S Teacher Education Program major. Differences in the NOS outcomes may be due to differences in the chosen antecedent predicator variables, but they may also be due to other differences in background and experiences not represented in the initial pool of participant characteristics under consideration. Another weakness is the inability of the researcher to manipulate the levels of predictor variables selected by the participants. There is the likelihood of other extraneous or confounding predictor variables within the group that have not been identified.

The threat of instrument decay to the internal validity of the study was lowered using several procedures. First, only one person, the researcher, scored the responses. This, however, may be another limitation of the method as researcher bias is not controlled. Second, participant responses for one target aspect of NOS were divided into two sets of equal number of participants. The first set was then scored. After a 1-hour break, the second set of participant responses for the same target aspect of NOS was scored. This was repeated later in the same day for a second target aspect of NOS. Over the span of several days, the same procedure was used to score participant responses on the additional target aspects of NOS. Third, additional iterations of this procedure were completed by the researcher to explore emerging themes in the data and to validate the structure of the scoring rubric and final scores for participant understanding of the target aspects of NOS. Fourth, the one administration of the VNOS-C questionnaire to the participants nullified any testing threat to internal validity.

A standardized protocol was used to administer the VNOS-C questionnaire and to conduct the semi-structure interviews in order to reduce the threat of data collector characteristics and bias. The semi-structured interview was used in an attempt to reduce the chances of using "leading questions" by the researcher. The attitude of the participants may have posed a threat to internal validity. The researcher who administered and scored the VNOS-C responses and conducted the interviews was the instructor of the science methods course for all Middle Childhood and AYA Science Education majors. These courses listed aspects of NOS as course objectives for these courses and involved the teaching and assessment of these aspects. Participants who were interviewed and were enrolled in these science methods courses taught by the researcher may have experienced an anxiety to “get the right answer;” perhaps to demonstrate they learned something to “gain” the researcher’s approval. Such anxiety may have provided greater motivation on the part of these participants to thoroughly and thoughtfully respond to questions compared to participants who were EC program majors who were not enrolled in these science methods courses. However, the researcher did not perceive any such displays of anxiety by the participants.

Some participants may have responded to the VNOS-C questions in a less than thorough or thoughtful manner due to the time of the data collection. Most participants were finishing their student-teaching experience and their last semester of the teacher education program and were graduating in 2 weeks. The distractions of the upcoming graduation ceremonies, related activities, and finalizing future plans may have generated a hurried and hasty approach to completing the questionnaire.

Internal validity and trustworthiness of the results are expected in part to be established by the richness of the data collected (Merriam, 2003b; Patton, 2002). The variety of data collection methods employed in the study, including questionnaires, semi-structured interviews, and document analyses, establishes the validity of the findings of the study by means of data triangulation (Maykut & Morehouse, 1994; Merriam; Patton; Ritchie, 2003). However, given these limitations inherent to ex-post facto research, there is a risk of improper interpretation especially in the attempt to assign causality to the predictor variables when the nature of ex-post facto research precludes such an interpretation. While a correlated and preceding relationship is necessary to infer a causal relationship, it is not sufficient (Asher, 1983; Fraenkel & Wallen, 2003; McCracken, 1991; Newman & Newman, 1994; Warmbrod & Miller, 1974).

External Validity. The small number of participants (*n* = 38) in the study does limit the usefulness of the findings and the extent to which the results can be generalized. When the group being studied is fairly small and narrowly defined (i.e., participants in a selected teacher education program), the results most often can only be applied to that group (Fraenkel & Wallen, 2003; Newman & Newman, 1994). However, generalization of the study is plausible if the group studied can be shown to be representative of a larger group on at least some relevant variables (Fraenkel & Wallen; Merriam, 2003b). The program examined in the study, like other teacher education programs in the state, is approved and accredited by the state Board of Regents, conforms to the state Department of Education requirements, and has similar core elements or transactions within each program major as prescribed by the state. The extent to which the context of the study is similar to other state teacher education programs and participant characteristics are similar to member characteristics of these programs will determine the usefulness of this study. Replication of this study with future cohorts in the teacher education program and with participants in other teacher education programs with both similar and different contexts would provide the additional data needed to strengthen the external validity.

Chapter 4: Results

Participants' formal education experiences in both high school and university settings were collected by means of data gathered from high school and college transcripts. Responses to the VNOS-C questionnaire were collated and coded. Statistical treatment was applied to the data collected to answer the research questions of this study. Research findings and the results presented in this chapter (a) describe participant demographics or characteristics related to formal education experiences, (b) describe participant understanding of the target aspects of NOS and the classification of these understandings, (c) identify correlations between participant understanding of the target aspects of NOS and participant characteristics and, (d) identify which set(s) of participant characteristics account for the variance in the understanding of the target aspects of NOS. Correlations between the target aspects of NOS are identified and reported. Thirty-eight participants from the teacher education program of a private midwest university provided the data examined. Participants were year-4 students in the 4-year program who were completing their student-teaching requirement; with the exception of 3 participants who completed the last field experience and had yet to begin their student teaching experience.

Participant Characteristics

Participants were in year 4 of a 4 year undergraduate teacher education program at a private, faith-based university in the midwest. Table 4.1 summarizes participant demographic characteristics. Females comprised 96% of the Early Childhood Education majors (EC), 86% of the Middle Childhood – Science Concentration majors (MC-S), and 33% of the Adolescent/Young Adult Science Education majors (AYA-S). Approximately two-thirds of the participants attended a public high school. For those who attended private high schools, 11 graduated from private, evangelical Christian high schools and one graduated from a parochial, Catholic high school. Several participants earned additional academic credentials. Table 4.1 notes that 8 participants declared and completed a second major. Three were enrolled in the EC program major and 2 of the 3 completed requirements for the Middle Childhood Education major; however, they did not complete the required courses for a concentration area to earn a license to teach middle school students. One EC major did complete and earn a license for AYA Social Studies. Five of the six AYA-S majors completed the requirements for a second major, which in each case related to their AYA-S program major. The two AYA-S Chemistry Education majors who participated earned a B.A. in chemistry and the four AYA-S Life Science major participants earned a B.A. in Biology. In all AYA-S cases, the participants needed to complete an additional 4 to 8 hours of chemistry or biology elective courses.

Predictor variables	*n*	%
Gender		
Female	32	84.2
Male	6	15.8
High School		
Public	24	63.2
Private	12	31.5
Home School	2	5.3
Program Major		
EC	25	65.8
MC-S	7	18.4
AYA-S	6	15.8
Second major	8	21.1
Specialty[a]	5	13.2
Math Concentration[b]	6	15.8
Principles of Biology course		
Enrolled	26	68.4
Transfer credit	7	18.4
CLEP®	2	5.3
Other[c]	3	7.9
Principles of Earth Science course		
Enrolled	31	81.6
Transfer credit	2	5.3
CLEP®	1	2.6
Other[d]	4	10.5
Physical Science for Teachers course		
Enrolled	28	73.7
Transfer credit	3	7.9
Other[e]	7	18.4

Note. [a]Multi-age special education endorsement. [b]Only available to Middle Childhood Education majors as one of two chosen concentrations. [c]AYA Life Science majors enrolled in the major's Biology majors course instead of Principles of Biology. [d]AYA Chem Ed majors enrolled in Environmental Chemistry. [e]AYA-S majors enrolled in science majors' physics courses.

Table 4.1. Descriptive statistics for participant demographic characteristics (*n* = 38).

Five participants in the EC program major completed the additional requirements for the multi-age special education licensure endorsement. None of the required additional courses for the multi-age special education endorsement were science content or science teaching specific. Participants completing the MC-S program major were required to have an additional concentration area along with the science concentration. Six of the seven participants in the MC-S program major chose the mathematics concentration and completed the required 24-27 semester hours of mathematics courses.

A common core of science courses is required in the teacher education program for most participants regardless of program major (see Table 4.1). All participants in the EC, MC-S, and with few exceptions AYA-S program majors in the teacher education programs are required to take and pass the Principles of Biology and the Principles of Earth Science courses. Both courses are credited toward participants' general education course requirements and are designed principally for the university's general student population. Participants who were AYA Life Science majors completed Introduction to Biology, a required course for Biology majors, in place of Principles of Biology. AYA-S Chemistry Education majors replaced credit for Principles of Earth Science with the successful completion of the Environmental Chemistry course. Physical Science for Teachers is a required science course for participants who are declared EC and MC-S majors. Physical Science for Teachers provides an introduction to core concepts of physics and chemistry for pre-service teachers.

Participants earned credit for the three common core courses either by (a) successful completion of the course with a minimum passing grade, (b) obtaining a score at or above a designated score on a specified CLEP exam, or (c) transfer credit for an approved course from another undergraduate higher education institution. Participants' performance in these courses is noted in Table 4.2. Mean and median grade averages approximated a grade of "B" or 3.00 grade points for both the Principles of Earth Science course (ESCIG) and the Physical Science for Teachers (PSTG) course. Participants' grades for the Principles of Biology grade (GBIOG) had a mean of approximately a B- grade and the median was close to a C+ grade. Participants had stronger performances in the Physical Science for Teachers (PSTG) and Principles of Earth Science (ESCIG) course work than in Principles of Biology (GBIOG). The ranges of grades were similar for Principles of Biology and Principles of Earth Science and greater than the range of grades in Physical Science for Teachers.

Participant characteristics measured by high school education outcomes and college education performance are listed in Table 4.2. Mean ACT Composite (ACTC), Mathematics (ACTM), and Science Reasoning (ACTS) scores were above the national average ($M = 21$). Participant scores for the ACT composite, ACT Mathematics, and ACT Science Reasoning are consistent with a Gaussian or normal distribution as determined by Pearson Chi square normality test (p=0.35, p=0.15, p=0.81, respectively). The university and teacher education program do not have stated minimum ACT scores as an entrance requirement, however, credentials of applicants with the best prospects for admission into the university included ACT or SAT scores above the national average. Other factors may also be considered in the admission process which may mitigate below average ACT or SAT scores. Several participants apparently had such factors.

Participants' high school experience as measured by their high school cumulative grade-point average (HSGPAC) and their grade-point average for all high school science courses (HSGPAS) were oriented to the high end of the grading scale (see Table 4.2).

The university requires a minimum "B" or 3.0 grade average for admission. All participants met the requirement and as a group exceeded the requirement (*M*=3.68).

	M	*SD*	*Mdn*	*Min*	*Max*	*Range*
ACTC[a]	24.11	4.11	23.50	15	32	17
ACTM[a]	23.36	4.19	24.00	14	33	19
ACTS[a]	23.45	3.74	23.18	14	32	18
HSGPAC[b]	3.68	0.30	3.79	3.01	4.00	0.99
HSGPAS[b]	3.52	0.46	3.56	2.25	4.00	1.75
HSSCI[c]	3.76	0.820	4.00	2	6	4
HSLS[c]	1.34	0.58	1.00	1	3	2
HSPS[c]	2.05	0.90	2.00	1	5	4
HSIS[c]	0.40	0.60	0.00	0	2	2
CGPA[b]	3.35	0.44	3.40	2.56	4.00	1.44
SGPA[b]	2.94	0.60	3.01	1.68	4.00	2.32
EGPA[b]	3.74	0.27	3.86	2.91	4.00	1.09
SCICH[d]	21.5	17.62	11	11	72.5	61.5
ESCIG[b]	2.92	0.71	3.00	1.00	4.00	3.00
GBIOG[b]	2.68	0.78	2.39	0.70	4.00	3.30
PSTG[b]	3.14	0.59	3.12	2.00	4.00	2.00

Note. [a] Based on a 36 point scale. [b] Based on a 4.00 scale. [c] Based on number of one-year high school credits. [d] Based on the number of college semester credit hours.

Table 4.2. Descriptive statistics for selected participant academic performance characteristics (*n* = 38).

The number of high school science credits completed (HSSCI) by participants (*M*=3.76; *Mdn*=4) suggests that many participants completed a college preparatory school curriculum. (One year of a science course is considered one science credit.) The ACT Corporation defines such a curriculum as a core curriculum which includes a minimum of three years of science courses (ACT, 2006). A minimum number of science credits is often required for high school graduation but not considered a separate requirement for admission into the university or its teacher education program. The mean grade-point average for participants' high school science courses (HSGPAS) was high (*M*=3.52) though several participants fell below 3.0. Participants' high school science courses grade-point averages were not directly considered in the admissions process into the university or teacher education program.

The types of science courses completed by participants in high school were categorized as: (a) life science (HSLS) which includes biology and human anatomy/physiology; (b) physical science (HSPS) which includes earth science, physical science, chemistry, and physics; and (c) integrated science (HSIS) which includes environmental science, STS (Science, Technology, and Society) courses and other designated "integrated" science courses. As a group, participants completed more physical science courses (*Mdn*=2) than life science (*Mdn*=1). This may be due to the requirements of the state and local school curriculum. For many participants, the first year science course in high school was either Physical Science or Earth Science, followed by Biology in year two. Many completed a Chemistry and/or Physics course as their third and fourth high school science credits. These courses are viewed as an integral component to a college preparatory curriculum (ACT, 2006). Taking Biology, Chemistry, and Physics courses for a high school science curriculum is linked with higher ACT scores and higher cumulative college grade-point averages (ACT). Thus a constraint may be placed upon the choices many college-bound students make regarding the type of high school science courses they choose as electives beyond the required courses. The number of credits for high school science credit hours in the participants' high school transcripts may reflect such restrictive choices. It was decided that in light of this situation the total number of high school science credit hours (HSSCI) would be used in the multiple regression analysis and the type of science credits, HSLS, HSPS and HSIS, would be excluded.

Normality checks using the Pearson Chi Square method indicated that the distribution of participant data in the cumulative high school grade-point average (HSGPAC), cumulative high school science courses grade-point average (HSGPAS), and the total number of high school science credits (HSSCI) variables were characteristics of data that was not sampled from a normal distribution ((p=.006, p=.04, p=.00000004 respectively). This is expected and reflects the population gaining entrance into traditional 4-year undergraduate institutions of higher education. The distribution of ACTC, ACTS, and ACTM scores were characteristic of a normal distribution.

Participants' mean grade-point average in the education designated courses (EGPA) was higher than both the mean grade-point average for college science courses (SGPA) and the cumulative college grade-point average (CGPA). The cumulative college grade-point average excludes the averaging of the grade points for all education courses and science courses. Participants as a group attained higher grades in the education course work component of their program and received their lowest grades in their science coursework.

Each transaction outcome was checked for normality using the Pearson Chi-square normality test. Two transaction outcomes, SGPA (*p*=.11) and CGPA (*p*=.15) suggested normal distribution. The data for the remaining transaction outcomes were inconsistent with a normal distribution. The EGPA outcome data had relatively few low values (skewness = -1.40) and the lowest variance (kurtosis = 1.17). The outcome variables for participant grades in Principles of Biology (GBIOG), Principles of Earth Science (ESCIG), and Physical Science for Teachers (PST) included mean grade-point averages for each respective course to fill several missing-data points which contributed to a lack of normality for these variables.

Participant Understanding of Aspects of NOS

Multiple iterations of analyzing participant responses to the VNOS-C questionnaire and interviews were completed to develop a rubric for each target aspect of NOS. The rubrics are found in Appendix C. Responses of participants were then classified and scored. The empirical (EMP), inferential (INF), theory-laden (THL), and social and cultural (SOC) aspects of NOS, and the distinction between a scientific law and theory (DLT) were scored as 0=Uninformed, 1=Syncretic (-), 2=Syncretic (+), and 3=Informed. Syncretic understandings are used to describe a continuum of understanding the target aspects of NOS between uninformed and informed. This category or classification represents a combination of some informed understanding or beliefs with those that are contradictory or do not align with an informed understanding. Syncretic (+) represents an understanding that conforms to a more informed understanding, having fewer inconsistencies between responses or fewer misconceptions than those responses categorized as syncretic (-). The tentative (TEN) aspect and the creative and imaginative

(CRI) aspect of NOS were scored as 0=uniformed, 1.5=syncretic, and 3=informed. Analysis of responses did not justify differentiating participant understanding into two levels of syncretic. However, the range of scores 0-3 was kept consistent for all aspects of NOS for regression analysis.

Table 4.3 presents the results of scoring participant responses on each target aspect of NOS. In three aspects, empirical (EMP), social and cultural (SOC), and creative and imaginative (CRI), more than one-third of participants' scores indicated an informed understanding. Responses on two aspects, inferential (INF) and distinction between a scientific law and theory (DLT) indicated that approximately 11% of participants had an understanding consistent with informed. The majority of participants understandings were categorized as syncretic – either syncretic (+) or syncretic (-) – for five of the seven target aspects of NOS. Most participants' understanding of these five aspects of NOS can be described as transitional between uninformed and informed. A majority of scores were categorized as uninformed view (55%) for the understanding of the distinction between a scientific law and scientific theory (DLT).

	Uninformed		Syncretic (-)		Syncretic (+)		Informed	
	No.	%	No.	%	No.	%	No.	%
EMP	4	10.5	12	31.5	4	10.5	18	47.4
INF	12	31.6	13	34.2	9	23.7	4	10.5
THL	10	26.3	5	13.2	13	34.2	10	26.3
DLT	21	55.3	9	23.7	4	10.5	4	10.5
SOC	8	21.1	9	23.7	7	18.4	14	36.8
				Syncretic				
TEN	3	7.9		26	68.4		9	23.7
CRI	3	7.9		22	57.9		13	34.2

Table 4.3. Participant scores on understanding the target aspects of NOS (*n* = 38).

More participants had an informed understanding of the empirical NOS (47.4%) as compared to a syncretic or uninformed understanding. The tentative (TEN), creative and imaginative (CRI), and empirical (EMP) aspects of NOS had the fewest participants' responses classified as uninformed understanding.

Empirical NOS. Nearly 50% of participant responses would be indicative of an informed understanding of the empirical (EMP) NOS (see Table 4.3). Many participants in their written responses to the VNOS-C used "concrete" to describe what science is and its basis. Interviews with participants were used to clarify the meanings of various terms such as "concrete" as it was used in the context of the responses. "Concrete" was exclusively used in an empirical sense, to refer to those things which can be observed with the different human senses. The terms "tangible", "natural" and, "grounded into the physical world" were also equated with an empirical meaning by some of the participants. Some participants used a very broad description of "experiment" to refer to any means used to gather data. Several referred to experiments as a "hands-on activity." Some participants who were EC majors conflated the term "experiment" with classroom pedagogy for teaching science. Others indicated in a strict sense that only through experimentation (as in using controls, independent variables, etc.) can scientific knowledge be advanced. The majority of responses which included these alternative terms or meanings came from participants who were EC program majors.

Inferential NOS. Participant responses regarding the inferential (INF) NOS were categorized as either uninformed (31.6%) or syncretic (-) (34.2%) while smaller percentages were considered either informed (10.5%) or syncretic (+) (23.7%) (see Table 4.3). The inferential aspect of NOS along with the distinction between a scientific law and a theory had the fewest number of participants with an informed understanding. Responses categorized as syncretic (-) or syncretic (+) refer to "interpretation" or "interpreting" data; however, they also contained contradictory statements such as "facts speak for themselves" or viewed a lack of data as the primary reason for the need for making interpretations or inferences. Participants tended to view some data sets as not open to interpretation while others were. In some cases this view of data sets was in the context of whether or not the observer starts with a theistic or atheistic worldview.

Theory-laden NOS. Participant responses were almost evenly distributed among uninformed, syncretic (+), and informed understanding of the theory-laden (THL) NOS with a smaller number categorized as syncretic (-) (see Table 4.30). The term "bias" was observed frequently and was used only with negative connotations in responses categorized as uninformed and syncretic (-). Responses scored as syncretic (+) used "bias" in a broader and more neutral sense to convey the role of human limitations in scientific endeavors. However, these responses did not delineate "bias" with regard to educational experiences, motivation, personal interest, etc. Several responses categorized as informed ascribed different interpretations of phenomena to "different ways of thinking" or "looking at it differently."

Distinction between a scientific law and theory NOS. The majority of responses were scored as uninformed (55.3%) regarding differentiating between and properly describing a scientific law and scientific theory (DLT). Many viewed laws as absolute, "100% proven" or "set in stone" as opposed to theories as "not 100% proven" and being more conjecture or opinion in nature. Responses categorized as syncretic (-) or syncretic (+) appropriately described either a scientific law or theory but contained misconceptions or contradictory statements. A prevalent misconception among participants was a perceived hierarchal relationship between laws and theories. The smallest percentage of participants had an informed understanding of this aspect compared to the other aspects with the exception of the inferential (INF) NOS which were at the same level.

Social and cultural NOS. Over one-third of all participants responses were classified as informed (36.8%) making the social and cultural (SOC) aspect of NOS second only to the empirical (EMP) aspect with regards to the number of participants with an informed understanding. Uninformed responses typically referred to the need for science to be "objective" and to "stand apart" from societal and cultural influences. Some respondents affirmed the influence of cultural norms and values on the scientific endeavor but their responses also included contradictions to this affirmation. Responses affirming and providing elaboration or examples of society and culture influencing science were categorized as informed. Many participants used the term “universal” in their responses as prompted by a question in the VNOS-C and this presented a challenge to the researcher. The challenge was in regards to interpreting participant responses and developing a rubric that accounted for the multi-faceted view of the term “universal” in the science education and science communities.

Many in the scientific community believe that while society and culture may influence the process of science, scientifically verified knowledge claims are held as universally true, regardless of culture (e.g., the scientific model of the atom, the process of natural selection, and laws that govern planetary motions are the same whether a person is Asian, European, or African). Members in the science education community take the position that the veracity of scientific claims are culture dependent, they are not universal. These positions have been hotly contested within and between the scientific and science education communities (Hodson, 1993; Luft, 1998; Matthews, 1994; Seigel, 1997). The scoring rubric which was developed emphasized the influence of social and cultural norms and values on the processes of science. Responses addressing scientific knowledge claims as universal were not considered as uninformed or syncretic unless the responses failed to address the role of society in doing science or had contradictory statements.

Tentative NOS. The tentative (TEN) aspect of NOS was one of two aspects that were scored using a four-point scale to describe participant responses but with only three categories of scores. Responses were scored as uninformed (0), syncretic (1.5), or informed (3) (see Table 4.3). Uninformed responses typically demonstrated a view of knowledge and truth as absolute, often using the terms “proved” and “proven.” Several participants used the term “discover” in conjunction with “proven.” By means of interviewing participants, “discover” was clarified to mean finding new data that would force a revision of models or theories. Several respondents indicated that science can and does change because some ideas are “just theories.” This type of response was interpreted to indicate participant lack of understanding of what a theory is but such statements were considered evidence to warrant a syncretic view of the tentative NOS rather than uninformed as participants appeared to associate the potential of some change with regard to scientific knowledge. The majority of participants’ responses were classified as syncretic. Many did not articulate specific circumstances or conditions which justify changes to scientific knowledge claims. Informed responses described scientific knowledge in terms of confidence and workability.

Creative and imaginative NOS. The creative and imaginative (CRI) aspect of NOS is the second of two aspects that described participant responses among three categories (see Table 4.3). Similar to the tentative aspect, only a small percentage of responses were categorized as uninformed. The majority of participants’ scores were categorized as syncretic. Syncretic responses emphasized that creativity and imagination were involved in some areas of the scientific endeavor, most notably developing experimental designs and techniques of data collection. However, they also stated that creativity and imagination are to be minimized or excluded from other areas such as data analysis, generating hypothesis, and building theories. Many equated the use of creativity and imagination in these areas as “bias.” Informed responses were characterized by the view that creativity and imagination are used in the entirety of scientific endeavors.

Correlations

A bivariate correlational analysis was conducted between participant characteristics described as antecedent and transaction predictor variables and scores on participant responses for each target aspect of NOS. Pearson Product-Moment Correlation Coefficients (*r*) were calculated for the pairwise models of predictor variables compared to the NOS outcome criterion variables. The Logic Process Model framework was used to sort the predictor variables into two groups, antecedent and transaction/transaction outcome. Antecedent and transaction/transaction outcome variables whose correlations were statistically significant ($r \geq 0.41$ at $\alpha = 0.01$) with at least one NOS outcome criterion variable (see Table 4.3 and Table 4.4) were entered into multiple regression analyses to determine best-fit models for both sets of predictor variables with NOS outcome criterion variables.

Antecedent predictor variables provided some measure of participant characteristics which were descriptive of the participant prior to entering the teacher education program and reflected to some degree experiences and performances that may influence their understanding of the target aspects of NOS. Correlation coefficients between the antecedent predictor variables and the NOS outcome criteria variables are listed in Table 4.4. The type of high school attended by the participant, the number of high school life-science courses, and the number of integrated science courses completed by the participant were not significantly ($r \geq 0.41$ at $\alpha = 0.01$) related to participant response scores regarding any target aspects of NOS. Though gender had a moderate and significant correlation to two target aspects of NOS, it was dropped from consideration for further multiple regression analysis. Females were more likely to be enrolled in the EC major of the teacher education program (63%) and of the 25 participants in the EC program major 24 were female (96%).

Variable	EMP	INF	TEN	CRI	DLT	THL	SOC
Gender[a]	.41*	.09	.14	.17	.46*	.28	.16
High School[a]	.20	.09	.12	.13	.17	.05	.10
ACTC	.39	.47*	.50*	.40	.51*	.15	.35
ACTM	.41*	.49*	.44*	.43*	.55*	.18	.35
ACTS	.47*	.45*	.43*	.37	.52*	.27	.42*
HSGPAC	.08	.24	.46*	.30	.40	.14	.38
HSGPAS	.15	.29	.35	.24	.39	.18	.42*
HSSCI	.43*	.27	.21	.46*	.32	.27	.26
HSLS[a]	-.01	.06	-.17	.04	.19	.05	-.17
HSPS[a]	.30	.30	.31	.42*	.34	.20	.47*
HSIS[a]	.20	-.09	-.03	.004	-.24	.08	-.14

Note. *Statistically significant at *p* = .01 level. [a] Variables were not used in multiple regression analysis.

Table 4.4. Correlation coefficients (*r*) for antecedent predictor variables and NOS outcome criterion variables.

Given that participants in the EC major were more likely to have uninformed views and syncretic (-) views and that MC-S and AYA-S majors were more likely to have syncretic (+) or informed understanding for each of the target aspects of NOS (see

Tables 4.27 – 4.33), the significant correlation between gender and the empirical (EMP) aspect of NOS and the distinction between a scientific law and theory (DLT) were interpreted to be related to program major (PROG) and not necessarily gender. Gender was thus excluded from multiple regression analyses.

The number of high school physical science credits was moderately correlated to two target aspects (CRI and SOC). Eighty-two percent of participants either had an equal number of physical science and life science credits/courses or fewer life-science credits/courses than physical science. This is more than likely due to high school curriculum and advising constraints previously discussed. Thus, this characteristic was excluded from the multiple regression analysis. The remaining six antecedents (ACTC, ACTM, ACTS, HSGPAC, HSGPAS, and HSSCI) had a significant correlation ($r \geq 0.41$ at $\alpha = 0.01$) with at least one NOS outcome and were included in the multiple regression analyses.

Transactions/transaction outcome variables indicate to some degree the experiences and performances within the teacher education program that may influence participant understanding of the target aspects of NOS. The transaction/transaction outcome predictor variables correlations with NOS outcome criterion variables are listed in Table 4.5. Completing a second major or completing an endorsement for a special education license did not have a significant correlation ($r \geq 0.41$ at $\alpha = 0.01$) with any target NOS outcomes. Participant enrollment in Principles of Biology (GBIO), Principles of Earth Science (ESCI), or Physical Science for Teachers (PST) did not significantly correlate ($r \geq 0.41$ at $\alpha = 0.01$) with any NOS outcome. Neither did earned credit for those courses by means of CLEP examinations or transfer credit. What did significantly correlate ($r \geq 0.41$ at $\alpha = 0.01$) with NOS outcomes was participant performance (GBIOG, ESCIG, and PSTG) in these required teacher education program courses as indicated in Table 4.5.

Variable	EMP	INF	TEN	CRI	DLT	THL	SOC
Program Major	.54*	.52*	.58*	.47*	.71*	.63*	.52*
Second major[a]	.20	.13	.33	-.01	.31	.29	.24
Special Education[a]	-.05	.03	-.11	.09	-.06	.07	-.10
Math Conc[a]	.22	.38	.40	.54*	.39	.28	.29
CGPA	-.03	.37	.48*	.25	.28	.11	.44*
SGPA	.12	.47*	.59*	.53*	.48*	.21	.51*
EGPA	.05	.25	.41*	.38	.25	-.08	.26
SCICH	.50*	.48*	.55*	.42*	.69*	.60*	.48*
GBIO[a]	-.12	-.28	-.10	-.18	-.31	-.02	-.07
GBIOG	.16	.38	.51*	.26	.42*	.29	.38
ESCI[a]	-.29	-.08	-.33	.10	-.29	-.22	-.11
ESCIG	.04	.33	.43*	.43*	.47*	.05	.33
PST[a]	-.36	-.25	-.35	-.06	-.49*	-.40	-.25
PSTG	.11	.31	.46*	.35	.30	.06	.37

Note. *Statistically significant at *p* = .01 level. [a] Variables were not used in multiple regression analysis.

Table 4.5. Correlations (*r*) between transaction/transaction outcome predictor variables and NOS outcome criterion variables.

As discussed previously, data was missing for several participants for each of these variables due to the issue of CLEP and transfer credits. A mean grade-point average was calculated for each course using grades for participants who completed the course. The mean grade-point average was used to fill in the missing data for the respective courses; Principles of Biology (24%), Principles of Earth Science (18%), and Physical Science for Teachers (26%).

There was a statistically significant negative correlation (r = -.49) between participant enrollment in the Physical Science for Teachers course (PST) and the distinction between a scientific law and theory (DLT). Participants who were EC program majors were more likely to have an uninformed or syncretic (-) understanding of the distinction between a scientific law and theory (DLT) (see Table 4.30). Physical Science for Teachers was a required course for all EC program majors but it was not required for AYA-S program majors who were scored either with a syncretic (+) or informed understanding. Mathematics concentration was moderately related to the creative and imaginative (CRI) NOS aspect (r =.54). However, this transaction was unique to the participants who were MC-S majors. Therefore, it was considered a feature of the MC-S program major and was excluded from the multiple regression analyses.

The program major and the total number of college science credit hours (SCICH) were the only variables significantly correlated ($r \geq 0.41$ at $\alpha = 0.01$) to all 7 target aspects of NOS. Participant cumulative university grade-point averages (CGPA) were significantly correlated to the tentative (TEN) and social and cultural (SOC) aspects of NOS. Cumulative grade-point averages of participants for university education courses (EGPA) were significantly correlated only to one outcome, the tentative (TEN) aspect of

NOS. Five target aspects of NOS, inferential (INF), tentative (TEN), creative and imaginative (CRI), distinction between a scientific law and theory (DLT), and social and cultural aspect (SOC) were significantly correlated to participant cumulative grade-point averages for university science courses. Table 4.6 lists the predictor variables selected for the multiple regression analysis.

	Participant Characteristics	
Antecedents	Transactions	Transactions Outcomes
ACT Composite Score (ACTC)	Program Major (PROG)	College GPA Cumulative (CGPA)
ACT Mathematics Score (ACTM)		Education Program GPA (EGPA)
ACT Science Reasoning Score (ACTS)		Science Courses GPA (SGPA)
		Science Content Credit Hours (SCICH)
HS GPA Cumulative (HSGPAC)		Principles of Biology Grade (GBIOG)
HS GPA Science Courses HSGPAS		
		Principles of Earth Science Grade (ESCIG)
HS Science Credits (HSSCI)		
		Physical Science for Teachers Grade (PSTG)

Note. HS refers to High School. Transaction pertains to university experiences and outcomes only.

Table 4.6. Selected antecedent, transaction/transaction outcome predictor variables.

Correlations among the selected antecedent variables from Table 4.6 were calculated using the Pearson Product-Moment Correlation method (see Table 4.7). Three of the six selected antecedent predictor variables in Table 4.6 had excessive correlation with each other indicating the possibility of multicollinearity. ACT Composite scores (ACTC), ACT Mathematics (ACTM), and ACT Science Reasoning (ACTS) scores were highly correlated with each other ($r > .80$).

Antecedent	1	2	3	4	5	6
1. ACTC	--	.89	.92	.55	.51	.18
2. ACTM		--	.82	.61	.49	.22
3. ACTS			--	.55	.58	.31
4. HSGPAC				--	.73	.38
5. HSGPAS					--	.40
6. HSSCI						--

Table 4.7. Intercorrelations between selected antecedent predictor variables.

Correlations among the selected transaction/transaction outcome variables from Table 4.6 were calculated using the Pearson Product-Moment Correlation method (see Table 4.8). The transaction predictor variable, program major (PROG), was highly correlated ($r = .97$) with the total number of science credit hours (SCICH) transaction outcome and the cumulative grade-point average for science courses (SGPA) was highly correlated ($r = .81$) to both participant grades for Principles of Earth Science (ESCIG) and Physical Science for Teachers (PSTG).

Transaction	1	2	3	4	5	6	7	8
1. PROG	--	.14	.18	.33	.97	.26	.21	.15
2. CGPA		--	.68	.79	.13	.60	.69	.58
3. EGPA			--	.74	.14	.50	.53	.51
4. SGPA				--	.31	.71	.81	.81
5. SCICH					--	.20	.22	.10
6. GBIOG						--	.43	.57
7. ESCIG							--	.58
8. PSTG								--

Table 4.8. Intercorrelations between transaction/transaction outcome predictor variables.

The variance inflation factor (VIF) was calculated for variables with high correlation ($r \geq .80$) found in the set of antecedent predictor variables and the set of transaction/transaction outcome predictor variables to check for multicollinearity. The antecedent predictor variables ACT Composite score (ACTC), ACT Mathematics score (ACTM), and ACT Science Reasoning score (ACTS) demonstrated multicollinearity (VIF < .20) as did the transaction/transaction outcome predictor variables program major (PROG), cumulative grade-point average for college science courses (SGPA), and college science credit hours (SCICH). The problem of multicollinearity was addressed by running a stepwise regression using only one of the highly correlated antecedent variables in the model, e.g., ACT Composite score (ACTC), and excluding the two other highly correlated variables, e.g., ACT Mathematics score (ACTM) and ACT Science Reasoning score (ACTS), to obtain the R^2 values for the best-fit antecedent model for each of the target aspects of NOS. This was repeated using ACT Mathematics score (ACTM) in the model and excluding the ACT Composite score (ACTC) and ACT Science Reasoning score (ACTS) variables. A third regression was done using ACT Science Reasoning score (ACTS) in the model and excluding the ACT Mathematics score (ACTM) and ACT Composite score (ACTC) variables. The variables in the best-fit antecedent predictor variable model with the highest R^2 value were chosen and entered into the combined model for each target aspect of NOS. The same procedure was followed for the transactions/transaction outcome predictor variables program major (PROG), cumulative grade-point average for college science courses (SGPA), and college science credit hours (SCICH).

A check for multicollinearity between the antecedent and transaction/transaction outcome predictor variables in the combined models was done by calculating Pearson Product-Moment Correlations between the selected antecedent and transaction predictor variables. Results are listed in Table 4.9. None of the transaction/transaction outcome predictor variables used in the combined models were highly correlated to the antecedent predictor variables used in the same models ($r \geq .80$). The potential threat of multicollinearity in the combined models is therefore low.

	Antecedents					
Transactions	ACTC	ACTM	ACTS	HSGPAC	HSGPAS	HSSCI
PROG	.37	.47	.42	.26	.23	.41
CGPA	.56	.56	.41	.55	.51	-.01
EGPA	.61	.66	.47	.56	.40	.20
SGPA	.71	.64	.63	.65	.54	.20
SCICH	.34	.46	.39	.25	.20	.39
GBIOG	.49	.46	.44	.51	.37	-.03
ESCIG	.56	.46	.49	.55	.44	.18
PSTG	.63	.51	.53	.52	.41	.07

Table 4.9. Correlations between selected antecedent and transaction predictor variables in the combined regression models.

Multiple Regression Analyses

Multiple regression analyses using a stepwise procedure were conducted to determine the best-fit models for the set of antecedent predictor variables and the set of transaction/transaction outcomes predictor variables for each target aspect of NOS (see Table 4.6 for the selected variables). The Akaike Information Criterion was used to choose the best-fit models. The best-fit model antecedent variables were then combined with the best-fit transaction/transaction outcomes variables for each respective aspect of NOS and a regression was performed on the combined predictor variables model. Table 4.10 is an example of the best-fit model summaries determined for the antecedent and transaction/ transaction outcomes variables as well as the combined model. Differences in the multiple squared correlation coefficients (ΔR^2) between the best-fit antecedent and combined models were used to determine the additional proportion of variance in participant response scores explained by the transaction/transaction outcomes. See Figure 3.1 and Multiple Regression Analyses in Chapter 3 for further discussion of this method. The Bonferonni Correction was used to compensate for the multiple comparisons that were performed simultaneously on the same data for the NOS outcome criterion variables. Significance levels for the combined models and the regression for the combined model variables was set at $p = .007$.

Adjusted R^2 values were required to be reported for each model since this study (a) used a number of independent variables – the antecedent and transaction/ transaction outcomes predictor variables – and (b) compared models with different numbers of the predictor variables (Garson, 2010). The regression formula is adjusted to penalize the value of R^2 as the number of independent variables increases: it is a compensation for one model having more degrees of freedom than another (Cottrell, 2003; Garson). Thus, if the addition of another variable(s) raises the adjusted R^2 value for a regression, that is an indication that the additional variable(s) has improved the model (Cottrell).

Empirical NOS. Participant response scores on the empirical aspect (EMP) of NOS were regressed on the set of antecedent predictor variables and on the set of transaction/transaction outcome predictor variables to generate a best-fit model for each. The best-fit models were combined and a regression analysis conducted. Table 4.10 summarizes the results from the best-fit antecedent and transaction/transaction outcome models and the combined model for the empirical aspect. The difference in R^2 values (ΔR^2) between the combined model and the best-fit antecedent model is reported. The transaction/transaction outcomes predictor variable(s) present in the combined model to which the change is attributed are identified. Each model was statistically significant at the p = .007 level.

Model: EMP	R^2	Adjusted R^2	Std. Error	F	df1	df2	p
Best-fit antecedents: ACTM, HSGPAC, HSSCI	.41	.36	0.80	7.82*	3	34	.0004
Best-fit transactions: PROG	.29	.27	0.95	14.9*	1	36	.0005
Combined: ACTM, HSGPAC, HSSCI, PROG	.46	.40	0.78	7.13*	4	33	.0003

	ΔR^2	Percent Gain	Transaction(s)	% of variance
Combined model compared to best-fit antecedent model	.05	13.7	Prog	12.1

Note. *Statistically significant at p = .007 level.

Table 4.10. Regression analysis model summaries for the empirical (EMP) aspect of NOS (n = 38).

The addition of the program major (PROG) accounted for an additional 5.6% of variance in participant responses beyond what is attributed to the variables in the best-fit antecedent model, a gain of 13.7%. The total amount of variance within participant response scores associated with the program major (PROG) of participants was approximately 12%. The increase in the adjusted R^2 values from the antecedent model to the combined model indicates that the addition of the program major (PROG) transaction improved the model's accounting for variance in participant response scores for the empirical (EMP) aspect. Regression analysis of the combined model produced results listed in Table 4.11. ACT Mathematics Scores (ACTM), high school cumulative grade-point averages (HSGPAC), and the number of high school science credits (HSSCI) had similar effects on the model as indicated by the beta weights (*β*). Participants' cumulative high school grade-point averages (HSGPA) had an inverse effect on participant response scores on the empirical (EMP) aspect compared to the other predictor variables. That is lower HSGPAC values are associated with higher scores for the empirical (EMP) aspect of NOS. The program major (PROG) of the participants had the smallest effect among the variables. However none of the predictor variables individually in the model were statistically significant at *p*=.007.

Combined model: EMP	*β*	*SE β*	*t*	*p*
Intercept	0.00	0.13	0.00	1.00
ACTM	0.44	0.18	2.48	.02
HSGPAC	-0.40	0.17	-2.34	.03
HSSCI	0.37	0.15	2.46	.02
PROG	0.29	0.16	1.84	.07

Table 4.11. Regression analysis for combined model variables for the empirical (EMP) aspect of NOS (n = 38).

Inferential NOS. The inferential (INF) aspect of NOS scores were regressed on the antecedent and transaction/transaction outcome variables. Table 4.12 summarizes the best-fit model for each regression and the regression results for the combined model.

Each model was statistically significant at the $p = .007$ level. The addition of the participants' program major (PROG) and cumulative college grade-point average (CGPA) resulted in a 55% gain in explained variance by the predicator variables. Together the two transaction/transaction outcome variables (PROG, CGPA) accounted for over 35% of the total variance in the combined model. The adjusted R^2 value increased from the antecedent model to the combined model indicating an improvement of the model with the addition of the two transaction/transaction outcome variables. However, the adjusted R^2 value did not change from the transaction/transaction outcome best-fit model to the combined model.

Model: INF	R^2	Adjusted R^2	Std. Error	F	$df1$	$df2$	p
Best-fit antecedents: ACTM	.24	.22	0.88	11.6*	1	36	.002
Best-fit transactions: PROG, CGPA	.36	.32	0.82	9.87*	2	35	.0004
Combined: ACTM, PROG, CGPA	.38	.32	.82	6.93*	3	34	.0009

	ΔR^2	Percent Gain	Transaction(s)	% of variance
Combined model compared to best-fit antecedent model	.14	55	PROG, CGPA	35.6

Note. *Statistically significant at $p = .007$ level.

Table 4.12. Regression analysis model summaries for the inferential (INF) aspect of NOS ($n = 38$).

Table 4.13 indicates that the program major (PROG) had the greatest effect (*β*) on the variance accounted for by the combined model for the inferential (INF) aspect of NOS, approximately twice the effect of ACT Mathematics scores (ACTM) and cumulative college grade-point averages (CGPA). None of the predictor variable betas in the combined model are statistically significant at the $p = .007$ level.

Combined model: INF	*β*	*SE β*	*t*	*p*
Intercept	0.00	.13	0.00	1.00
ACTM	0.19	0.19	1.01	.32
PROG	0.40	0.16	2.60	.01
CGPA	0.21	0.17	1.27	.21

Table 4.13. Regression analysis for combined model variables for the inferential (INF) aspect of NOS ($n = 38$).

Theory-laden NOS. The summary of regression models for the theory-laden (THL) aspect of NOS are listed in Table 4.14. Both the best-fit transaction/transaction outcome model and the combined model were statistically significant at the $p = .007$ level. However, the best-fit antecedent model is neither statistically significant nor accounts for more than 7% of the variance related to participant response scores on the theory-laden (THL) aspect of NOS. This result for the best-fit antecedent model was expected and consistent with the lack of correlation between any antecedent variables and the theory-laden aspect (THL) of NOS (see Table 4.5). The number of high school science credits (HSSCI) in the best fit model was not significantly correlated with this target aspect of NOS (r = .27). Combining the best-fit transaction/ transaction outcomes variables program major (PROG), participants' grades in the Principles of Earth Science course (ESCIG), and grade-point average for education courses (EGPA) increased the amount of variance in participant response scores accounted for by nearly 629% for 86% of the variance. The combined model explained the highest amount of variance in theory-laden (THL) scores (R^2 = .51). However, there was no difference between the adjusted R^2 values for the combined and best-fit antecedent models. The additional antecedent variable, the number of high school science credits (HSSCI), in the combined model did not improve the best-fit transaction/ transaction outcomes model.

Model: THL	R^2	Adjusted R^2	Std. Error	F	$df1$	$df2$	p
Best-fit antecedents: HSSCI	.07	.05	0.98	2.84	1	36	.10
Best-fit transactions: PROG, EGPA, GBIOG	.50	.45	0.74	11.2^{*}	3	34	.00003
Combined: HSSCI, PROG, EGPA, GBIOG	.51	.45	0.74	8.57	4	33	.00007
	ΔR^2	Percent Gain	Transaction(s)			% of variance	
Combined model compared to best-fit antecedent model	.44	629	HSSCI, PROG, EGPA, GBIOG			86.2	

Note. *Statistically significant at p = .007 level.

Table 4.14. Regression analysis model summaries for the theory-laden (THL) aspect of NOS (n = 38).

The combined model regression analysis in Table 4.15 identifies only one of the predictor variables, program major (PROG), as a statistically significant contributor to the model at the *p* = .007 level. The program major (PROG) also had the largest partial effect (β) on the model, nearly one-and-one-half times the effect of both participants' grades in the Principles of Biology course (GBIOG) and grade-point average for education courses (EGPA) and more than three times that of the number of high school science credits (HSSCI). Participants' grade-point average for education courses (EGPA) was inversely related to their theory-laden aspect scores. A higher grade-point average for a participant's education courses (EGPA) is associated with lower scores for understanding the theory-laden (THL) aspect of NOS.

Combined model: THL	β	$SE\ \beta$	t	p
Intercept	0.00	.12	0.00	1.00
HSSCI	0.12	0.14	0.89	.38
PROG	0.56	0.14	3.99^{*}	.0004
EGPA	-0.37	0.15	-2.51	.02
GBIOG	0.33	0.15	2.21	.03

Note. *Statistically significant at *p* = .007 level.

Table 4.15. Regression analysis for combined model variables for the theory-laden (THL) aspect of NOS (*n* = 38).

Distinction between a scientific law and theory NOS. Table 4.16 summarizes the results for the best-fit antecedent, best-fit transaction/transaction outcome, and combined model regressions on participant response scores on the distinction between a scientific law and theory (DLT) aspect of NOS. Each model was statistically significant at the $p = .007$ level. The R^2 value for the combined model was increased by nearly 82% over the best-fit antecedent model. Program major (PROG) and participants' grades in the Principles of Earth Science course (ESCIG) accounted for 45% of the variance attributed to the combined model for participant response scores. The adjusted R^2 value increased with the addition of the best-fit transaction/transaction outcomes variables to the best-fit antecedent model. Comparing adjusted R^2 values between the best-fit transaction/ transaction outcomes model and the combined model showed a decrease in the adjusted R^2 value for the combined model.

Model: DLT	R^2	Adjusted R^2	Std. Error	F	$df1$	$df2$	p
Best-fit antecedents: ACTM, HSSCI	.35	.31	0.83	9.22 *	2	35	.0006
Best-fit transactions: PROG, ESCIG	.61	.59	0.64	27.6 *	2	35	.0000001
Combined: ACTM, HSSCI, PROG, ESCIG	.63	.58	0.65	13.9 *	4	33	.000001

	ΔR^2	Percent Gain	Transaction(s)	% of variance
Combined model compared to best-fit antecedent model	.28	81.7	PROG, ESCIG	44.9

Note. *Statistically significant at $p = .007$ level.

Table 4.16. Regression analysis model summaries for the distinction between a scientific law and theory (DLT) aspect of NOS ($n = 38$).

In the regression analysis for the combined model summarized in Table 4.17, only the transaction/transaction outcome variable program major (PROG) was statistically significant at the p = .007 level and it also had the largest effect (β) having more than twice the effect of participants' grades in the Principles of Earth Science course (ESCIG) and nearly four times the effect of participants' ACT Mathematics (ACTM) scores. The partial effect of the number of high school science credits (HSSCI) was nearly negligible at 1/50th of that of ACT Mathematics (ACTM) scores.

Combined model: DLT	β	$SE\ \beta$	t	p
Intercept	0.00	0.11	0.00	1.00
ACTM	0.15	0.13	1.15	.26
HSSCI	0.003	0.12	-0.03	.98
PROG	0.58	0.13	4.50 *	.0001
ESCIG	0.28	0.12	2.34	.03

Note. *Statistically significant at p = .007 level.

Table 4.17. Regression analysis for combined model variables for the distinction between a scientific law and theory (DLT) aspect of NOS (n = 38).

Social and cultural NOS. Regression analysis summaries for the predictor variable models associated with the social and cultural (SOC) aspect of NOS are listed in Table 4.18. The best-fit antecedent model was not statistically significant at the p = .007 level. However, the two variables in the model were both moderately and significantly correlated to the social and cultural aspect (r = .42 in both cases, see Table 4.5). The best-fit transaction model and the combined model were statistically significant at the p =

.007 level. The addition of the program major (PROG) and participants' cumulative college grade-point average (CGPA) nearly doubled the amount of variance explained in the social and cultural (SOC) aspect scores. Though the R^2 value was highest for the combined model, its adjusted R^2 value was not higher than that of the best-fit transaction model. The combined model with four antecedent and transaction/transaction outcome predictor variables was an improvement over the best-fit antecedent model but it was not an improvement over the best-fit transaction model with two predictor variables.

Model: SOC	R^2	Adjusted R^2	Std. Error	F	$df1$	$df2$	p
Best-fit antecedents: ACTS, HSGPAS	.22	.18	0.91	5.01	2	35	.01
Best-fit transactions: PROG, CGPA	.41	.38	0.79	12.2*	2	35	.0001
Combined: ACTS, HSGPAS, PROG, CGPA	.43	.36	0.80	6.3*	4	33	.0007

	ΔR^2	Percent Gain	Transaction(s)	% of variance
Combined model compared to best-fit antecedent model	.21	94	PROG, CGPA	48.5

Note. *Statistically significant at p = .007 level.

Table 4.18. Regression analysis model summaries for the social and cultural (SOC) aspect of NOS (n = 38).

Regression analysis results for the combined model are listed in Table 4.19. The program major of the participants (PROG) was the only statistically significant individual variable in the model and also had the greatest partial effect (β). It had one and one-half times the effect of the other transaction variable, participants' cumulative college grade-point average (CGPA), and over two and one-half times participants' high school grade-point averages for science courses (HSGPAS). ACT Science Reasoning scores (ACTS) had a minimal partial effect in the model.

Combined model: SOC	β	$SE\ \beta$	t	p
Intercept	0.00	0.13	0.00	1.00
ACTS	0.02	0.17	0.13	.90
HSGPAS	0.16	0.17	0.93	.36
PROG	0.43	0.14	3.04*	.005
CGPA	0.29	0.15	1.85	.07

Note. *Statistically significant at $p = .007$ level.

Table 4.19. Regression analysis for combined model variables for the social and cultural (SOC) aspect of NOS ($n = 38$).

Tentative NOS. Table 4.20 summarizes the results for the best-fit antecedent, best-fit transaction/transaction outcome, and combined models for regression of the predictor variables on participant scores for the tentative aspect (TEN) of NOS. Each model is statistically significant at the $p = .007$ level. The addition of the best-fit transaction/transaction outcome variables increased the amount of variance explained by the combined model by 82% and the variables themselves accounted for 45% of the total variance. The adjusted R^2 value increased for the combined model compared to the best-fit antecedent model. However, the adjusted R^2 value actually decreased between the best-fit transaction/transaction outcome model and the combined model. The additional variables in the combined model did not improve the model's accounting for variance in participant response scores over the best-fit transaction/transaction outcome model.

Model: TEN	R^2	Adjusted R^2	Std. Error	F	$df1$	$df2$	p
Best-fit antecedents: ACTC, HSGPAC	.30	.26	0.86	7.33*	2	35	.002
Best-fit transactions: PROG, CGPA, PSTG	.53	.49	0.71	12.9*	3	34	.00001
Combined: ACTC, HSGPAC, PROG, CGPA, PSTG	.54	.47	0.73	7.44*	5	32	.0001

	ΔR^2	Percent Gain	Transaction(s)	% of variance
Combined model compared to best- fit antecedent model	.24	82	PROG, CGPA, PSTG	45.1

Note. *Statistically significant at $p = .007$ level.

Table 4.20. Regression analysis model summaries for the tentative (TEN) aspect of NOS ($n = 38$).

The regression analysis results for the combined model for the tentative (TEN) aspect of NOS listed in Table 4.21 found that of the five predictor variables in the model only the program major (PROG) was significant at the $p = .007$ level. The program major (PROG) also had the greatest partial effect (β) on the model, doubling and tripling the effect of the next most effective predicator variables, cumulative college grade-point average (CGPA) and participants' grades in the Physical Science for Teachers course (PSTG) respectively. Participants' cumulative high school grade-point average (HSGPAC) had one-half the effect of the PSTG variable and ACT Composite scores

(ACTC) had the least effect in the model, at 1/50 the effect of program major. Both the ACT Composite scores (ACTC) and cumulative high school grade-point average (HSGPAC) variables are antecedent predictor variables.

Combined model: TEN	*β*	*SE β*	*t*	*p*
Intercept	0.00	0.12	0.00	1.00
ACTC	0.01	0.18	0.05	.96
HSGPAC	0.09	0.16	0.57	.57
PROG	0.50	0.13	3.77 *	.0007
CGPA	0.25	0.16	1.54	.13
PSTG	0.18	0.17	1.09	.29

Note. *Statistically significant at p = .007 level.

Table 4.21. Regression analysis for combined model variables for the tentative (TEN) aspect of NOS (n = 38).

Creative and imaginative NOS. Models for the best-fit antecedent variables, the best-fit transaction/transaction outcome variables and the combined predictor variables for participant response scores for the creative and imaginative (CRI) aspect of NOS are summarized in Table 4.22. Each model was statistically significant at the p = .007. Combining the best-fit antecedent and transaction/transaction outcome models produced a 27% gain in explaining the variance among creative and imaginative aspect scores over the best-fit antecedent model. The improvement in the adjusted R^2 value between the two models confirmed the improvement of the combined model over the antecedent model by adding the program major (PROG) and participants' grades in the Principles of Earth

Science course (ESCIG). The two transaction/transaction outcome variables accounted for almost 22% of the variance in participant response scores for the creative and imaginative (CRI) aspect of NOS.

Model: CRI	R^2	Adjusted R^2	Std. Error	F	$df1$	$df2$	p
Best-fit antecedents: ACTM, HSSCI	.33	.30	0.84	8.55^*	2	35	.0009
Best-fit transactions: PROG,ESCIG	.34	.30	0.84	8.97^*	2	35	.0007
Combined: ACTM, HSSCI, PROG, ESCIG	.42	.35	.81	5.93^*	4	33	.001

	ΔR^2	Percent Gain	Transaction(s)	% of variance
Combined model compared to best-fit antecedent model	.09	27	PROG, ESCIG	21.5

Note. *Statistically significant at $p = .007$ level.

Table 4.22. Regression analysis model summaries for the creative and imaginative (CRI) aspect of NOS ($n = 38$).

The regression analysis for the combined model for the creative and imaginative (CRI) aspect of NOS is summarized in Table 4.23. The transaction/transaction outcomes program major (PROG) and participants’ grades in the Principles of Earth Science course (ESCIG) had similar effects (β) with the number of high school science credits (HSSCI), an antecedent variable, in the model. Each had approximately six to seven times greater effects over ACT Mathematics scores (ACTM) in the model. None of the betas for the individual variables were statistically significant at $p = .007$.

Combined model: CRI	*β*	*SE β*	*t*	*p*
Intercept	0.00	.13	0.00	1.00
ACTC	0.04	.17	0.84	.41
HSSCI	0.29	.15	1.95	.06
PROG	0.23	.16	1.44	.16
ESCIG	0.27	.15	1.79	.08

Table 4.23. Regression analysis for combined model variables for the creative and imaginative (CRI) aspect of NOS (n = 38).

Regression Analyses Summary

The frequency of variables in each of the best-fit antecedent models is represented in Table 4.24. ACT scores were present in six of the seven models and the model where they were absent and not statistically significant explained little variance among participant response scores for the target aspect of NOS (theory-laden). ACT Mathematics scores (ACTM) and the number of participants' high school science credits (HSSCI) were present in four of the best-fit models. ACTM and HSSCI occurred together in three of the models (EMP, CRI, and DLT). The HSSCI variable was the only variable present in the one non-significant model (THL). ACTM was the only variable present in the INF model. Other ACT scores, Composite (ACTC) and Science Reasoning (ACTS), were each present in one model but their individual effect (*β*) was not statistically significant. Only the ACTM and HSSCI variables had a statistically significant effect in some models.

NOS Aspect	ACTC	ACTM	ACTS	HSGPAC	HSGPAS	HSSCI
EMP		√$^{*\,H}$		√		√*
INF		√*				
THL						√
DLT		√^{*H}				√
SOC			√		√^{H}	
TEN	√^{H}			√		
CRI		√				√^{H}

Note. *Statistically significant at *p* = .007 level. ^{H} Highest partial effect in the model.

Table 4.24. Frequency of the antecedent predictor variables in the best-fit models for the NOS outcome criterion variables.

One variable in each multivariate best-fit antecedent model had a greater partial effect than others. However, in four of the five multivariate models, the partial effect of each variable was similar to the other(s). Only the best-fit antecedent model for the distinction between a scientific law and theory had a variable (ACTM) with greater effect than other variables in the model.

The frequency of variables in each of the best-fit transaction models for the target aspects of NOS is represented in Table 4.25. Participants' program major (PROG) was present in each of the models and its effect was statistically significant in six of the seven models at the *p* = .007 level. The program major variable was not statistically significant in the model for the empirical (EMP) aspect of NOS. However, the *p* value was small enough (*p* = .008) to warrant consideration as significant. The partial effect of the program major was the highest among all variables in the multivariate transaction models.

NOS Aspect	PROG	CGPA	EGPA	GBIOG	ESCIG	PSTG
EMP	√*					
INF	√^{*H}	√				
THL	√^{*H}		√	√		
DLT	√^{*H}				√*	
SOC	√^{*H}	√				
TEN	√^{*H}	√				√
CRI	√^{*H}				√	

Note. *Statistically significant at $p = .007$ level. ^{H} Highest partial effect in the model.

Table 4.25. Frequency of the transaction/transaction outcome predictor variables in the best-fit models for NOS outcome criterion variables.

The cumulative college grade-point average of participants (CGPA) was present in three of the best-fit transaction models but in no model was it statistically significant. The possible exception is the regression model on the social and cultural (SOC) aspect of NOS where $p = .007$. Only participant grades in the Principles of Earth Science course (ESCIG), along with the program major, were statistically significant in any regression model.

The frequency of predictor variables in the combined regression models are listed in Table 4.26. The significance and level of effect (β) for several variables changed as they were moved into a combined model from the original best-fit antecedent or transaction models. ACT Composite scores (ACTC), ACT Mathematics scores (ACTM), and participants' high school grade-point averages for science courses (HSGPAS) declined in effect relative to other variables in the combined models. ACT Mathematics scores (ACTM) and the number of participants' high school science credits (HSSCI) remained as the variables with the greatest partial effect in two of the combined models (EMP and CRI respectively). None of the variables which were statistically significant contributors to the best-fit antecedent models were statistically significant contributors to their respective combined models. The program major (PROG) continued to be statistically significant in four of the seven combined models. It was significant in six of the best-fit transaction models (Table 4.25). The program major (PROG) had the highest partial effect in five of the combined models compared to having the highest in six best-fit transaction models. Other transaction/transaction outcome variables were not statistically significant in the combined models for the NOS outcome criterion variables. The program major variable seemed to be an integral member in most of the best-fit transaction models and combined models.

	ACTC	ACTM	ACTS	HSGPAC	HSGPAS	HSSCI	PROG	CGPA	EGPA	GBIOG	ESCIG	PSTG
EMP		√^{H}		√		√	√					
INF		√					√^{H}	√				
THL						√	√^{*H}		√	√		
DLT		√				√	√^{*H}				√	
SOC			√		√		√^{*H}	√				
TEN	√			√			√^{*H}	√				√
CRI		√				√^{H}	√				√	

Note. *Statistically significant at $p = .007$ level. ^{H} Highest partial effect in the model.

Table 4.26. Frequency of antecedent, transaction, and transaction outcome predictor variables in the combined models for NOS outcome criterion variables.

Program Major and the Target Aspects of NOS

The program major (PROG) variable is a transaction variable of interest based on the results listed in Table 4.25. It had the highest partial effect in five of the combined models and had the highest effect and was statistically significant in six best-fit transaction models. Participants' response scores for each target aspect of NOS were compared with the program major variable. Results of the comparisons are listed in Tables 4.27 through 4.33 and are discussed in the following section.

Empirical NOS. Table 4.27 compares results of participant scores for the empirical aspect (EMP) of NOS by participant program major. The EC program major had the lowest percentage of its participants (28%) with an informed understanding of the empirical (EMP) aspect of NOS. Fewer participants had a syncretic (+) (12%) understanding. The majority of EC participants were syncretic (-) (44%). The EC program major was the only program major with participants who had an uninformed understanding (16% of the EC program major participants). The majority of participants enrolled in the MC-S program major (72%) had informed understanding while only 2 MC-S participants (28%) had either a syncretic (-) or syncretic (+) understanding. No MC- participants had an understanding categorized as uninformed. All AYA-S participants (100%) had an informed understanding of the empirical (EMP) aspect of NOS. Testing the differences between the program major scores as statistically significant was not possible given the MC-S and AYA-S populations were too small. However, at a glance, it appears participant understanding of the empirical (EMP) aspect of NOS were more likely to be informed if they were enrolled in the MC-S or AYA-S program majors and uninformed or syncretic if they were enrolled in the EC program major.

Program Major	Participant Understanding: EMP Uninformed		Syncretic (-)		Syncretic (+)		Informed	
	No.	%	No.	%	No.	%	No.	%
EC *n* = 25	4	16	11	44	3	12	7	28
MC-S *n* = 7	-	-	1	14	1	14	5	72
AYA-S *n* = 6	-	-	-	-	-	-	6	100

Table 4.27. Participant understanding of the empirical (EMP) aspect of NOS by program major.

Inferential NOS. Table 4.28 compares results of participant scores for the inferential (INF) aspect of NOS by participant program major. No participant enrolled as an EC program major had an informed understanding. A small number of participants in the EC program major had a syncretic (+) view (16%). The majority of responses for participants' in the EC program major were either syncretic (-) (40%) or uninformed (44%). The majority of participants enrolled in the MC-S program major (43%) had an informed view of the inferential (INF) aspect of NOS. The remaining MC-S program major participant responses were categorized as syncretic (+) (29%), syncretic (-) (16%), or as uninformed (16%). One AYA-S program major participant (17%) had an informed view of the inferential (INF) aspect of NOS. The remaining participant responses were categorized as either syncretic (+) (50%) or syncretic (-) (33%). No responses from participants enrolled in the AYA-S program major were categorized as uninformed. The majority of uninformed scores for all participants were among EC program majors (11 of 12 or 92%). Participants enrolled in the MC-S program had the greatest number of informed views (3).

Program Major	Participant Understanding: INF Uninformed		Syncretic (-)		Syncretic (+)		Informed	
	No.	%	No.	%	No.	%	No.	%
EC *n* = 25	11	44	10	40	4	16	-	-
MC-S *n* = 7	1	14	1	14	2	29	3	43
AYA-S *n* = 6	-	-	2	33	3	50	1	17

Table 4.28. Participant understanding of the inferential (INF) aspect of NOS by program major.

Theory-laden NOS. Table 4.29 compares results of participant scores for the theory-laden (THL) aspect of NOS by participant program major. Only one participant (4%) in the EC program major had an informed understanding of the theory-laden (THL) aspect of NOS. Most EC program major participant responses were categorized as either syncretic (+) (40%) or uninformed (40%). A small number of participant responses

(16%) in the EC program major were categorized as syncretic (-). The majority of participants (57%) enrolled in the MC-S program major had an informed understanding of the theory-laden aspect of NOS. Fewer MC-S participants had responses categorized as syncretic (+) (29%) and syncretic (-) (14%). No MC-S participant response was categorized as uninformed. All but one AYA-S program major participants had their responses classified as informed (83%). The remaining participant response was categorized as syncretic (+). None of the p AYA-S program major participant responses were categorized as syncretic (-) or uninformed. All uninformed responses were among those participants enrolled as EC program majors.

Program Major	Participant Understanding: THL							
	Uninformed		Syncretic (-)		Syncretic (+)		Informed	
	No.	%	No.	%	No.	%	No.	%
EC *n* = 25	10	40	4	16	10	40	1	4
MC-S *n* = 7	-	-	1	14	2	29	4	57
AYA-S *n* = 6	-	-	-	-	1	17	5	83

Table 4.29. Participant understanding of the theory-laden (THL) aspect of NOS by program major.

Distinction between a scientific law and theory NOS. Table 4.30 compares results of participant scores for the distinction between a scientific law and theory (DLT) aspect of NOS by participant program major. None of the participants enrolled in the EC program major had responses that were categorized as informed or syncretic (+). A small percentage of EC program major participant responses (24%) were categorized as syncretic (-) while the majority of responses were categorized as uninformed (76%). Views of the distinction between a scientific law and theory (DLT) from participants in the MC-S program major were distributed along the entire range of scores. The percentage of MC-S program major participant responses categorized as informed, syncretic (+), and uniformed was the same (29%). One MC-S participant response (14%) was categorized as syncretic (-). Views of participants in the AYA-S program major were distributed evenly among the informed, syncretic (+), and syncretic (-) categories (33% respectively). None of the AYA-S program participant responses were categorized as uniformed. Similar to the results for the empirical (EMP), inferential (INF), and theory-laden (THL) aspects of NOS, the majority of uninformed views of the distinction between a scientific law and theory were found among participants enrolled in the EC program major (90%).

Program Major	Participant Understanding: DLT Uninformed		Syncretic (-)		Syncretic (+)		Informed	
	No.	%	No.	%	No.	%	No.	%
EC *n* = 25	19	76	6	24	-	-	-	-
MC-S *n* = 7	2	29	1	14	2	29	2	29
AYA-S *n* = 6	-	-	2	33	2	33	2	33

Table 4.30. Participant understanding of the distinction between a scientific law and theory (DLT) aspect of NOS by program major.

Social and cultural NOS. Table 4.31 compares results of participant scores for the social and cultural (SOC) aspect of NOS by participant program major. A number of responses from participants in the EC program major were categorized as informed (16%) or syncretic (+) (20%) for the social and cultural (SOC) aspect of NOS. The majority of EC program major participant responses, however, were categorized as syncretic (-) (36%). Seven EC program major participant responses (28%) were scored as uninformed. Six of the 7 participants (86%) in the MC-S program major had informed responses for participant understanding of the social and cultural (SOC) aspect of NOS. One (14%) MC-S participant response was categorized as uninformed. All AYA-S major responses were classified as informed. The majority of responses categorized as uninformed or syncretic (-) are from participants enrolled in the EC program major.

Program Major	Participant Understanding: SOC							
	Uninformed		Syncretic (-)		Syncretic (+)		Informed	
	No.	%	No.	%	No.	%	No.	%
EC *n* = 25	7	28	9	36	5	20	4	16
MC-S *n* = 7	1	14	-	-	-	-	6	86
AYA-S *n* = 6	-	-	-	-	2	33	4	67

Table 4.31. Participant understanding of the social and cultural (SOC) aspect of NOS by program major.

Tentative NOS. Table 4.32 compares results of participant scores for the tentative (TEN) aspect of NOS by participant program major. Only one response (4%) from participants enrolled in the EC program major was categorized as informed for the tentative (TEN) aspect of NOS. The majority of responses (84%) for participants in the EC program major were categorized as syncretic and a smaller percentage (12%) of responses was categorized as uninformed. The majority of participant responses in the MC-S program major were categorized as informed (57%) with the remainder categorized as syncretic (43%). None of the participants enrolled in the MC-S program major had responses to the tentative (TEN) aspect of NOS scored as uninformed. Similar to the results of participants enrolled in the MC-S program major, the majority (67%) of AYA-S program major participant responses were categorized as informed with the remainder (33%) categorized as syncretic. None of the responses from participants in the

AYA-S program major were scored as uninformed. Similar to the empirical (EMP) and social and cultural (SOC) aspects of NOS, all uninformed responses among participants in the teacher education program for the tentative (TEN) aspect of NOS were held by those enrolled in the EC program major.

Program Major	Participant Understanding: TEN					
	Uninformed		Syncretic		Informed	
	No.	%	No.	%	No.	%
EC *n* = 25	3	12	21	84	1	4
MC-S *n* = 7	-	-	3	43	4	57
AYA-S *n* = 6	-	-	2	33	4	67

Table 4.32. Participant understanding of the tentative (TEN) aspect of NOS by program major.

Creative and imaginative NOS. Table 4.33 compares results of participant scores for of the creative and imaginative (CRI) aspect of NOS by participant program major. A small percentage (12%) of responses from participants enrolled in the EC program major were categorized as informed for the creative and imaginative (CRI) aspect of NOS. The majority of responses (76%) for EC program major participants were categorized as syncretic and a small percentage (12%) of participant responses were categorized as uninformed. All MC-S participant responses (100%) were categorized as informed for the creative and imaginative (CRI) aspect of NOS. Responses for participants enrolled in the AYA-S program major were evenly distributed between informed and syncretic understanding of the creative and imaginative (CRI) aspect of NOS. Similar to the empirical (EMP) and social and cultural (SOC), and tentative (TEN) aspects of NOS, all uninformed responses among participants in the teacher education program for the creative and imaginative (CRI) aspect of NOS were held by those enrolled in the EC program major.

	Participant Understanding: CRI					
Program Major	Uninformed		Syncretic		Informed	
	No.	%	No.	%	No.	%
EC *n* = 25	3	12	19	76	3	12
MC-S *n* = 7	-	-	-	-	7	100
AYA-S *n* = 6	-	-	3	50	3	50

Table 4.33. Participant understanding of the creative and imaginative (CRI) aspect of NOS by program major.

Intercorrelations Among Aspects of NOS

Intercorrelations between participant responses to target aspects of NOS were calculated using the Pearson Product-Moment Correlation. Table 4.34 lists the coefficient (*r*) for each bivariate correlation. Two aspects, theory-laden (THL) and creative and imaginative (CRI), were significantly related ($r \geq 0.41$ at $\alpha = 0.01$) to all other target aspects. The inferential (INF) and tentative (TEN) aspects, and the distinction between a scientific law and theory (DLT) were each significantly related to five of the six target aspects. The empirical (EMP) and social and cultural (SOC) aspects were significantly related to four and three aspects respectively.

Transaction	1	2	3	4	5	6	7
1. EMP	--	.40	.37	.47	.56	.47	.30
2. INF		--	.46	.58	.59	.59	.52
3. TEN			--	.53	.60	.53	.57
4. CRI				--	.50	.47	.49
5. DLT					--	.51	.39
6. THL						--	.69
7. SOC							--

Table 4.34. Intercorrelations between target aspects of NOS outcome criterion variables.

Document Analyses

Planning guides for the respective majors in the teacher education program, science content course syllabi, and science teaching methods course syllabi were examined to identify features which distinguish the majors from each other and which may be related to participant understanding of the target aspects of NOS.

Teacher education program planning guides. The types of participant experiences or transactions in the teacher education program were contingent upon the program major selected by the individual participant. An analysis of the student planning guides for the EC, MC-S, and AYA-S program majors revealed common requirements regarding course work and several key distinctions. Table 4.35 summarizes the comparisons between the three different program majors.

All participants in this study completed the same eight required education courses (12 total credit hours) referred to as the Teacher Education Core. Often participants in different program majors were enrolled in the same sections of these core courses. Participants were also required to complete the same core of science courses: Principles of Earth Science and Principles of Biology with the exception of AYA Life Science Education majors who were required to successfully complete the Introduction to Biology course, a course designed for all Biology majors. Physical Science for Teachers was required for all EC and MC-S majors as were two mathematics courses – Principles of Mathematics I & II. AYA-S majors were required to complete one of two designated Physics courses and either a Pre-calculus or Calculus course as specified by the specific AYA-S program major (e.g., Life Science Education, Chemistry Education, etc.).

The teacher education program majors differed in several ways. First, the total number of science credit hours required differed for each major. This difference was expected given the context of science teaching for each major. Second, the programs differed in the total number of credit hours earned in education courses and in the organization of the curriculum. The university's teacher education program organized many of the education courses into clusters or blocks where the courses complemented one another and involved team teaching. Table 4.35 identifies three block arrangements for the EC majors and two for the MC-S and AYA-S majors.

Teacher Education Program Major		
Early Childhood: EC	Middle Childhood-Science Concentration: MC-S	Adolescent/Young Adult Science Education: AYA-S
TEP core curriculum	TEP core curriculum	TEP core curriculum
Education Block Courses		
Early Childhood Foundations	Middle Childhood Methods I	Introduction to Teaching
Early Childhood Methods I	Middle Childhood Methods II	Principles of Teaching
Early Childhood Methods II		
Student-Teaching	Student Teaching	Student Teaching
Total credit hours: 69	Total credit hours: 54	Total hours credit hours: 43
Required Science Credits		
Principles of Earth Science	Principles of Earth Science	Principles of Earth Science
Principles of Biology	Principles of Biology	Principles of Biology[*]
Physical Science for Teachers	Physical Science for Teachers	Discipline specific science courses.
	Prescribed science courses	
Total credit hours: 11	Total credit hours: 28	Total credit hours: 49-52
Required Math Credits		
Principles of Mathematics I & II	Principles of Mathematics I & II	Precalculus or Calculus I, II, III. (Prescribed by discipline)
Total credit hours: 6	Total credit hours: 6	Total credit hours: 4-13

Note: [*] Adolescent/Young Adult Life Science Education majors replaced this credit with Introduction to Biology.

Table 4.35. Comparison of the different teacher education program major requirements.

Many of the courses in the blocks were unique to specific teacher education program members. For example, both the Early Childhood Foundations and Early Childhood Methods I included several courses designed for language arts and reading strategies for younger children.

The Middle Childhood Methods I block courses included a course on Middle School issues. These courses were neither suited nor appropriate for inclusion in the Introduction to Teaching block for AYA-S majors. There were several courses that were common to two or more different program majors' block education courses but none were related to science teaching pedagogy.

The teacher education program majors differed as well in regard to the total number of education course hours. The total education course hours for the EC program major was nearly 38% greater than the number of education credit hours required in the AYA-S program major. The total required number of education credits decreased for program majors that lead to licensure for teaching in the higher grade levels. Correspondingly, the total number of required science credits increased for teaching in the higher grade-levels. This is a reflection of the need for teachers to have more expertise in specific disciplines and fields to effectively teach in the content-driven middle and high school classrooms.

A fourth difference was found in the learning objectives of the science teaching methods courses which were unique to each program major. The syllabi for the Teaching Science: Early Childhood, Teaching Science: Middle Childhood, and Teaching Science: Adolescent/Young Adult were examined to delineate differences between the courses and determine if the courses related in any way to the seven target aspects of NOS. The results of that analysis are discussed in the following section.

Course syllabi. Science content course syllabi for each science course that a participant in the teacher education program could enroll in were examined. Course descriptions, course objectives and/or goals, and assessments listed or described in these syllabi were analyzed to identify any explicit reference to NOS including the seven target aspects in this study. Only one of the three syllabi for the required science courses common to each of the three program majors included any explicit references to NOS. The syllabus for Principles of Biology included three objectives related to NOS including the methods of scientific inquiry. The NOS objectives in this course were assessed using multiple-choice questions and a written course assignment. The syllabi for Principles of Earth Science and Physical Science for Teachers did not contain any references to aspects of NOS or methods of science. It was not determined if participants who transferred in credit for Principles of Biology or Principles of Earth Science were explicitly taught NOS aspects. The face-to-face version of the Principles of Biology course was exclusively taught by the researcher. Participants who were EC program majors were required to complete these three science courses and only these courses to meet the science credit hour requirement.

In addition to the three science courses previously discussed, participants who were MC-S majors completed an additional 17 credit hours of science content courses. Two courses in the MC-S curriculum directly or indirectly referenced NOS aspects. The Concepts in Middle School Science course was introduced into the MS-S curriculum for

Spring Semester 2005. The course was developed by a now retired faculty member to meet specific Ohio Department of Education academic content standards for middle school educators. Standards addressed in this course included tenets of NOS. Six of the 10 course objectives directly or indirectly connected to each of the target aspects of NOS in this study. Class members were assessed on NOS aspects by open-response and forced-choice exam questions and two writing projects. The second course, Environmental Science for Middle School Educators, included course objectives which referenced the social and cultural NOS and those objectives were assessed by open-response and forced-choice exam questions and one presentation project. Both courses were taught by the researcher.

The AYA-S program major required the greatest number of science credit hours, up to five times more than EC participants. An examination of the available syllabi for the science courses that were required or served as electives revealed that most aspects of NOS were not explicitly described, listed as course objectives, nor assessed. Not one of the target aspects was explicitly or directly identified in the examined syllabi. The social and cultural NOS was indirectly described with course objectives and/or assessments for several courses. It was mentioned in the context of science, technology, and society issues and applications of course content. One course, General Ecology, indirectly referenced the distinction between a scientific law and theory in one course objective. Only AYA Life Science Education majors were required to complete this course. Most science course syllabi specifically referred to methods of science and scientific inquiry in their course descriptions and objectives. The extent to which related aspects such as the empirical and inferential NOS were elucidated in these courses in relationship to the methods of science could not be determined. Several courses used projects to assess participants' understanding and use of scientific methods. Whether the projects presented other aspects of NOS for consideration could not be determined.

Syllabi for the respective program majors' science teaching methods courses were also examined to identify any explicit reference to NOS including the target aspects in this study. Course descriptions, course objectives and/or goals, and assessments listed or described in these syllabi were perused. The syllabus for the EC program major science teaching methods course only referred to NOS outcomes in one broad objective regarding participants' "understanding content knowledge in early education (… and the history and nature of science.)" No other references were made to aspects of NOS in the course objectives. References were not made to any NOS outcomes in assessment descriptions nor the schedule of topics listed in the syllabus. Several interviewed participants who were enrolled in the EC program major did not recall any type of evaluation in the science teaching methods course related to NOS or any discussion related to NOS.

The MC-S and AYA-S program majors each included one science teaching methods course for participants. Both courses included many of the same objectives and listed similar topics in the course syllabus (as one would expect). The researcher taught both courses and modified each to conform to the specific requirements for each program major. Both courses indirectly referenced aspects of NOS in a course objective which stated participants will "understand the curricular requirements of the Ohio Academic Content Standards for Science… ." However both methods courses directly addressed

NOS as a topic for class discussion and lecture in the syllabus and both listed NOS activities in the course schedule of topics. Aspects of NOS were assessed in a variety of ways according to both syllabi. Assessments included (a) “writing an essay describing what science is and what distinguishes it from other ways of knowing,” (b) constructing concept maps using aspects of NOS, (c) developing a lesson plan for the appropriate grade-level using activities to teach students various aspects of NOS, and (d) selecting articles from popular media outlets for use in teaching aspects of NOS.

Chapter 5: Conclusions and Implications

This chapter presents (a) a summary of the study, (b) the conclusions drawn from the study, (c) implications, and (d) suggestions for further study. A restatement of the problem and research questions and a brief review of the procedures employed in conducting the research are presented in the summary of the study. Major findings and their interpretation are presented in the conclusions section. Implications of the findings and suggestions for further research conclude the chapter.

Summary of the Study

Science for All Americans (1990) and the *National Science Education Standards* (1996) specifically address aspects of NOS throughout the K-12 science curriculum and have influenced the science standards adopted by many states and their respective departments of education. As an example of their influence, aspects of NOS are explicitly stated as benchmarks and grade level indicators in the academic content standards for the state of Ohio (Ohio Department of Education, 2003). It is thus incumbent upon Ohio educators in K-12 settings to instruct and facilitate student understanding of NOS. In this context, the current study was conducted to examine preservice teachers' understanding of aspects of NOS and identify factors within a teacher education program which may impede or promote understanding NOS aspects. The specific questions answered by this study are:

1. What understanding do the participants of the teacher education program at a Midwestern liberal arts university near the completion of their licensure programs have of aspects of nature of science?
2. Would teacher education participants' understanding aspects of nature of science align with an informed, an uninformed, or a syncretic understanding of nature of science?
3. What variables or factors discriminate between the different levels of understanding aspects of NOS among the teacher education participants?

The VNOS-C questionnaire was used to elicit participant understanding of seven target aspects of NOS. Each participant was in year 4 of a four year undergraduate teacher education program at a private Ohio university. Follow-up interviews were conducted with 50% of the participants to establish validity. Participant high school and university transcripts were examined and data recorded. Data were organized into antecedent predictor variables, transaction predictor variables, and NOS outcome criterion variables based upon the Logic Model Process. Correlations were determined between the predictor variables and each NOS outcome criterion variable. Variables with a statistically significant correlation ($r \geq 0.41$ at $\alpha = 0.01$) to any one of the seven target NOS outcomes were selected for regression analyses (with some exclusions). Figure 5.1 identifies the selected antecedent and transaction variables in relationship to the theoretical framework of this study.

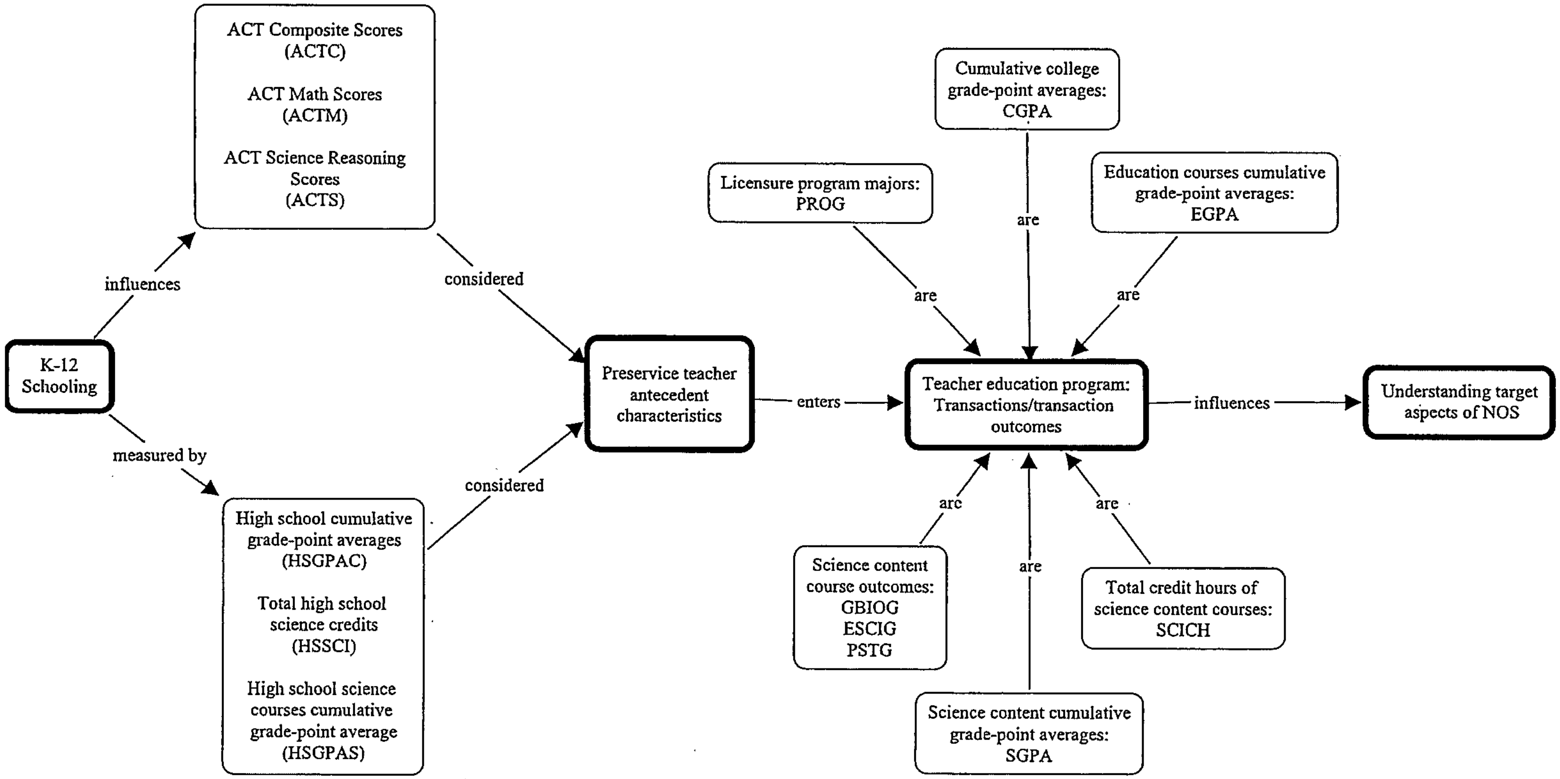

Figure 5.1. Relationship of the selected predictor variables to the development of preservice teacher understanding of NOS.

Regression analyses were used to determine the best combination of antecedent and transaction variables accounting for the most variance in NOS outcomes among participants and to identify which variables had the most effect in the best-fit and combined regression models.

Conclusions

Conclusions from the result of the study follow. They are arranged in a logical progression starting with participants' understanding of the target aspects of NOS and concluding with the identification of factors related to the development of these understandings. Discussion of each conclusion is included.

1. The majority of participants did not have an informed understanding of any of the seven aspects of NOS examined. Some participants responses were classified as informed on each of the target aspects, others uninformed but the majority of responses were either syncretic (-) or syncretic (+) for the inferential (INF), theory-laden (THL), the distinction between a scientific law and theory (DLT), and the social and cultural (SOC) aspects of NOS and syncretic for the tentative (TEN) and creative and imaginative (CRI) aspects of NOS. Responses classified as syncretic included some facet of the aspect appropriately articulated by the participants; however, there were inconsistencies, misconceptions, or contradictions in their responses. The results that participant understanding was at different levels may indicate that their understanding of NOS progresses through stages, illustrating Vosniadou's mental model hypothesis (Vosniadou, 1994, 1999, 2002, 2003; Vosniadou & Brewer, 1994; Vosniadou et al., 2004.). This progression of understanding is also implied in the work of Akerson et al. (2007). This

study suggests that the mode of representation for participant understanding for each target aspect of NOS is best viewed along a continuum from uninformed to informed with the majority of participant responses situated somewhere between the two.

The distinction between a scientific law and theory is the one aspect where the majority of participants' responses (55%) were classified as uninformed. This is problematic as the chief aim of science is theory building and constructing laws to explain how the natural world works (AAAS, 1990; NRC, 1996). It is difficult to imagine how these future teachers will facilitate the development of an informed understanding of what science is and how it works among their students when they lack such understanding. Why is the distinction between a scientific law and theory the aspect least understood among participants? One explanation may involve the impediment of global worldviews (Abd-El-Khalick & Akerson, 2004). Many responses used theory in the context of the origin of life controversy. "Just a theory" was often invoked to discredit evolution as an explanation for the origin of life and to mollify its seeming contradiction to their religious world views. If participants used the term theory in such a way, by extension they may be compelled to use the term in this inappropriate manner in other scientific contexts for the sake of internal congruency. A second reason may involve the use of theory in popular culture and press. Often theory is used in the sense of possible explanations to a crime scene, fluctuations in the stock market, etc. These "theories" often change as events and circumstances unfold giving a temporary and ephemeral nature to the meaning of theory from which the participants use of the term does not appear to be insulated.

Participants’ misconceptions related to the other target aspects of NOS were similar to the common misconceptions identified in the literature (Abd-El-Khalick, 2005; Abd-El-Khalick & Lederman, 2000a, 2000b; Clough, 2000; McComas, 1996, 1998; Ryan & Aikenhead, 1992). Many participants viewed science knowledge as having proven ideas that cannot be changed. Scientific knowledge is described or viewed as absolute and is knowledge that is discovered. Scientists are seen applying a particular methodology, the experiment, and using induction to unequivocally prove some concept or fact. Data analysis, data interpretation, and establishing theories are to be devoid of any individual or societal bias or interference. These methods of science are straightforward and sterile. Cultural norms and values should not play a role in the scientific endeavor. They are not viewed as contributing in any way to the construction of scientific knowledge. Indeed many participants do not see scientific knowledge as constructed knowledge but rather as discovered.

2. As antecedents, the number of high school science credits and ACT mathematics, composite, and science reasoning scores are important factors related to developing participants’ understanding of NOS in the teacher education program. ACT scores were present in the best-fit models of regression for six of the seven NOS outcomes examined in this study. The ACT mathematics score was present in the best-fit models for four NOS outcomes, ACT science reasoning score for one, and ACT composite score for one other. The best-fit regression model for theory-laden NOS did not include any ACT score variable but it was not statistically significant ($p > .007$) and accounted for only 7% of the variance in the scores. Participants who enter the teacher

education program with higher ACT composite, mathematics, and science reasoning scores are more likely to have a more informed understanding of the empirical, inferential, creative and imaginative, social and cultural, and tentative NOS. Given their high intercorrelation (ACTM ~ ACTC, $r = .89$; ACTS ~ ACTC, $r = .92$; ACTM ~ ACTS, $r = .82$) any one of the three ACT scores may be an important factor in explaining the amount of variance for understanding these aspects of NOS. (As discussed in chapter 3, only one ACT score was permitted into the full model for regression analysis).

Though the tests which comprise the ACT exam do not explicitly measure student understanding of the seven target aspects of NOS (ACT, 2010a), the relationship between the three ACT scores and NOS outcomes may in part be explained by a factor linked to NOS outcomes identified by Abd-El-Khalick and Akerson (2004). They listed learning orientation as a factor which may promote or hinder the development of understanding NOS. The authors contrasted deep orientation to surface orientation; describing deep orientation as a view of learning where congruency between ideas is sought, terminology of the discipline is mastered, and the terminology of the discipline is consistently used. Learners who displayed these qualities of deep orientation toward learning were more likely to have informed views of NOS compared to those who did not. Those who did not were characterized as having a surface orientation to learning. The ACT exam is curriculum based and measures academic achievement in select areas (ACT, 2010b). Higher ACT scores may reflect a more accurate and rich understanding of terms, concepts, principles, and their relationship to one another in the discipline the test seeks to measure. A participant's ACT scores may thus be indicative of the type of learning orientation he/she has. Higher ACT scores may mean a participant possess a deep orientation to learning that relates to higher scores on NOS outcomes in this study.

In addition to higher ACT scores, the greater the number of high school science credits earned, the more likely a participant was to score higher on the NOS outcomes. The number of high school science credits was present in the best-fit antecedent models for 4 NOS outcomes; empirical, creative and imaginative, theory-laden, and the distinction between a scientific law and theory. The best-fit regression model for theory-laden NOS was not statistically significant ($p > .007$). In the other three best-fit antecedent regression models, the ACT mathematics score was present with the number of science credit hours. The relationship between the number of high school science credits and NOS outcomes may be explained in part by the increase in the number of opportunities (with the increase in science courses) to learn requisite concepts, terms, etc. to developing informed understandings of NOS in the context of the teacher education program. Though NOS may not be explicitly included in course objectives or explicitly taught in these high school science courses, completing more high school science courses implies the participant knows more scientific terms, understands more concepts, is acquainted with more models, encounters more theories, and makes more connections between them. Thus, a participant may build a richer framework on which to develop an understanding of NOS when NOS is encountered as explicit content in higher education. The additional course work may also initiate or continue a deep orientation to learning previously discussed.

Two other participant antecedents were present among three of the best-fit antecedent regression models. High school cumulative grade-point average was present in the model for the empirical and tentative NOS and participants' high school grade-point average for science courses was present in the social and cultural NOS. However, only participants' high school grade-point average for science courses was statistically significant in any of the regression models. The presence of high school grade-point average for science courses (HSGPAS) in so few models is viewed with caution so as not to overestimate its role as a factor in the development of participants' understanding of NOS.

3. Teacher education program features or transactions are related to participants' understanding of the target aspects of NOS. The amount of explained variance in participants' responses for the inferential (INF), theory-laden (THL), the distinction between a scientific law and theory (DLT), social and cultural (SOC), and tentative (TEN) aspects of NOS increased by more than 50% with the addition of the best-fit transaction variables to the best-fit antecedent models. For each, the adjusted R^2 values were higher for the best-fit transaction/transaction outcome compared to the best-fit antecedent model and the adjusted R^2 values for the combined antecedent and transaction model for each of the five aspects remained unchanged or decreased compared to the best-fit transaction model for the respective aspects. If there is not a change in the adjusted R^2 values with the addition of other variables, there is no improvement to the explanatory power of the model with the additional variables. It can therefore be inferred that only transaction variables are necessary to explain a portion of the variance seen in

participants' responses and the antecedent variables have little value. Caution must be exercised in making such a conclusion – the differences in the adjusted R^2 values should not be over-interpreted and the importance of the antecedent variables minimized. The Logic Model Process emphasizes a temporal relationship between the antecedent and transaction variables. Based on adjusted R^2 values, it may appear the antecedent variables contribute little. However, the antecedents have been shown to be related to NOS outcomes and they do precede the transactions in the life history of the participants. They are economically significant and should not be ignored.

4. The type of program major in the teacher education program is an important factor in developing participants' understanding of each target aspect of NOS. The program major was present in the best-fit transaction model for each of the target aspects and was statistically significant in six of the models (the exception was the creative and imaginative aspect of NOS). It also had the greatest effect (β) in all models with two or more transaction variables. When the best-fit transaction models were combined with the best-fit antecedent models for each target aspect of NOS, only the program major was statistically significant and had the greatest effect (β) in the regression model for four aspects (tentative, theory-laden, social and cultural NOS, and the distinction between a scientific law and theory). The other three models did not have any statistically significant individual variables.

5. Participants who are EC program majors are more likely to have uninformed or syncretic (-) of the empirical (EMP), inferential (INF), theory-laden (INF), the distinction between a scientific law and theory (DLT), and the social and cultural (SOC) aspects of

NOS. MC-S and AYA-S program majors were more likely to have informed or syncretic (+) understandings of these same aspects and informed understandings of the tentative (TEN) and creative and imaginative (CRI) aspects. Program majors were assigned ranked values for the regression analysis based on the number of science credit hours required in the individual majors. Thus, EC program majors were ranked as 0, with 11 science credit hours required; MC-S program majors were ranked as 1 with 28 required science credit hours; and AYA-S program majors were ranked as 2, with 49-56 science credit hours required in the program. This strategy of ranking the majors thus permits a direct correspondence of the program major to scores on the rubrics used to evaluate participants' understanding aspects of NOS.

Tables 4.27 through 4.33 provide additional support for the claim that participants in the EC program major were more likely to have lower scores for understanding the target aspects of NOS. The highest percentages of participants with an informed or syncretic (+) understanding of the empirical (EMP), inferential (INF), theory-laden (THL), the distinction between a scientific law and theory (DLT), and social and cultural (SOC) aspects of NOS were MC-S and AYA-S program majors. None of the responses for EC program major were categorized as informed on the inferential NOS and the distinction between a scientific law and theory. The small number of participants in the MC-S (*n*=7) and AYA-S (*n*=6) did not permit an analysis of variance between the three program majors to determine if the differences in participants' response scores on each aspect of NOS was statistically significant. However, the regression analyses and the data in Tables 4.27 through 4.33 support the conclusion that the program major is a key factor in participants developing an informed understanding of the target aspects of NOS.

6. The number of science content courses influences the development of understanding of the target aspects of NOS. The EC program major requires the fewest with 11, the MC-S requires more than double the number with 28, and the AYA-S major requires the most with a range of 49-55 based on the specific discipline. Such differences may influence participants developing an informed understanding of the target aspects of NOS in several ways. First, as discussed previously, the additional courses may provide a richer framework of concepts, terminology, examples, etc. on which to further develop NOS constructs. Completing fewer science courses may hamper participants who are EC program majors in developing informed views of NOS. Learning science and the related aspects of NOS takes time in order to restructure previous knowledge and to develop appropriate scientific constructs (Hewson, 1981; Posner et al., 1982; Strike & Posner, 1992; Vosniadou, 1999, 2002; Vosniadou et al., 2001, 2004). Participants in the EC program major have fewer chances in college, compared to participants in the MC-S and AYA-S program majors, to restructure and interact with scientific concepts and terminology including NOS tenets. There is less time to develop a rich framework upon which to develop appropriate NOS constructs and fewer opportunities for EC program major participants to reflect upon their views of science, its nature, what it is, and reconcile those views with their global worldviews.

Second, participants in the MC-S and AYA-S program majors continue with science content courses into year three and in some cases year four of the teacher education program. Participants in the EC program major are expected to complete the three required science content courses by the end of year two in the program. There is an interval of at least one year or more between completing the last science content course and enrollment in the science methods course, Teaching Science: Early Childhood. It is suggested that such a lapse diminishes the opportunities for participant reflection associated with developing informed NOS views (Scharmann et al., 2005). Any informed understanding of NOS aspects developed may be lost or replaced due to a time lapse in applying their science content knowledge to methods of teaching science.

Third, fewer science course requirements in the EC program major may limit the opportunities for participants to internalize the importance of NOS. Abd-El Khalick and Akerson (2004) identify this as a factor which hinders development of the understanding of NOS. Lederman (1992) comments that the degree to which a teacher subscribes to the importance of NOS will determine the level of understanding among his/her students. The limited number of science courses and the scant attention given to NOS in the EC program major curriculum and the level of understanding of the seven target aspects of NOS among its participants may support such a claim by Lederman.

Implications

The findings and conclusions from this study suggest that the Early Childhood program major curriculum at the university where this study was conducted needs to be revised if the majority of participants are to graduate with an informed understanding of the target aspects of NOS. The revisions may have implications for other teacher education programs which prepare preservice teachers to teach science in K-12 classrooms. However, given the study's small population and ex-post facto design, the reader is cautioned to carefully consider the context of this study and identify corroborating evidence from other, similar contexts when evaluating the merits of the suggested implications. Replications of this study are needed to further investigate, test, and validate the relationship of the examined variables, notably ACT scores and the number and types of science courses, to understanding the seven target NOS aspects. With this caveat, this study has several implications.

1. Teacher education program participants' understanding of NOS should be evaluated along a continuum and not simply as informed or uninformed. Participants may have misconceptions or contradictions but the majority holds to some correct proposition concerning NOS. Identifying the correct facets as well as misconceptions provides a starting point to begin moving the participant to a more informed understanding and provides a framework for faculty to begin addressing specific misconceptions. Though not evident in any course experiences examined in this study, conceptual change instructional strategies may be useful for moving preservice teachers from uninformed to informed understandings as suggested by Akerson et al. (2000). Pre- and post-tests of teacher education program participants views of the target aspects of NOS would be useful in measuring actual gains in understanding that may be attributed to specific teacher education program features.

2. Teacher education programs may want to consider the role and use of ACT scores for recruitment and admission into teacher education programs preparing preservice teachers to teach science in any grade level. Consideration should be given as

well to the minimum number of high school science courses required for admission. Participants in this study with higher ACT scores and a higher number of high school science credits were more likely to develop informed views of the target aspects of NOS. Candidates seeking admission to teacher education programs who do not meet the higher standards may be required to successfully complete an additional university science course as prerequisite for admission into the teacher education program. The prerequisite course should include explicit NOS instruction integrated with other science discipline concepts and principles.

3. The teacher education program may want to consider developing an explicit-reflective NOS curriculum for use, with proper contextual adaptations, in each of the program major science teaching methods courses. An explicit NOS pedagogy would include explicit NOS learning outcomes, the use of classroom activities and instructional methods focused on NOS outcomes, varied assessments of those outcomes, and preservice teacher reflection assignments regarding NOS. The teaching science methods courses for both the MC-S and AYA-S program majors included explicit instruction and assessment on the target aspects of NOS. Such explicit instruction was not evident in the EC program major teaching science methods course.

4. Teacher education programs should consider examining the use of collaboration between the instructors of requisite science courses in each of the licensure programs, especially in early childhood or early elementary. Such collaboration could develop common and explicit NOS learning outcomes among the courses. Instructors of these courses should be encouraged to further collaborate on the formation and

development of context specific activities to facilitate participant understanding of NOS learning outcomes. With the common theme of NOS present in each of their required science courses, participants in the early childhood majors may be more inclined to realize the importance of NOS in developing scientifically literate students in addition to reflecting on their own understanding which promotes the development of more informed understanding.

5. The evaluation methods used in this study may serve as a template for evaluating other teaching education programs in regards to participants' understanding of NOS. Most teacher education programs in Ohio (88%) include the three primary teaching licenses; Early Childhood, Middle Childhood, and Adolescent/Young Adult (Ohio Department of Education, n.d.). The approach used in this study to examine participants in each of these program majors may be useful to identify features specific to one facet of the program which promotes an informed NOS understanding. Once identified, the feature(s) can be integrated into the teacher education program. In other words, such an examination may identify what the specific teacher education program is doing well with regard to developing particular understanding of the target aspects of NOS and apply these features in some manner across the program to promote understanding among all participants required to teach the content of NOS.

Suggestions for Further Research

The current study explored and categorized teacher education program participants' understanding of the empirical (EMP), inferential (INF), theory-laden (THL), the distinction between a scientific law and theory (DLT), social and cultural

(SOC), tentative (TEN), and creative and imaginative (CRI) aspects of NOS. It also identified and examined participants' characteristics which may influence their understanding of those aspects of NOS. In relationship to the findings of this study, further research is recommended to investigate the following areas:

1. Comparisons between participants in the teacher education program and university students who are not education majors are needed to determine if there are differences and the extent of these differences in understanding NOS. Such comparisons would be useful to investigate further the suggestion that the number of science credit hours completed by each participant is related to and influences participants' understanding of the target aspects of NOS. For example comparing AYA Life Science majors to Biology majors with similar science content course requirements may provide insight into the extent that the number of science credit hours influences NOS understanding and the influence of other factors such as science teaching methods courses.

2. A number of studies were referenced to prepare a scoring scheme to categorize participants' responses on the VNOS-C questionnaire and in these studies there was an apparent lack of consistency or common constructs in the scoring methods employed. Research is needed to standardize and validate a common rubric to evaluate preservice teachers' understanding of NOS. A standardized rubric would allow understanding NOS comparisons across studies and present a larger data set in which to apply appropriate research tools to uncover related factors and conditions.

3. Replications of this study are needed to determine if the results are valid and if so further investigations are required to investigate the relationship between academic variables and teacher education program participants' understanding of aspects of NOS. Carey and Stauss (1968, 1969, and 1970) found no relationship between certain academic variables and preservice and experienced science teachers' conceptions of NOS. Lederman (1992a), in a review of NOS research in science education, endorsed the findings of Carey and Stauss by summarily stating academic variables are not related to NOS conceptions. However, the results of this study may indicate otherwise. A limitation of the work of Carey and Stauss was the use of a forced-choice instrument to evaluate participant understanding of NOS – the Wisconsin Inventory of Science Processes (WISP). Carey and Stauss looked at the broad perspective of NOS to find correlations. The use of the VNOS-C in this study provided a finer gradation to determine participant views on more specific aspects of NOS and may have provide more useful data to examine the relationships between academic variables and NOS conceptions. A re-examination of the relationship between academic variables and NOS conceptions using other instruments such as the VNOS questionnaires may be in order.

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Appendix A

VNOS-C Questionnaire Items Aligned to Target Aspects of NOS

	VNOS-C Questionnaire Items	Aspect of NOS
1.	What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?	Empirical
2.	What is an experiment?	Empirical
3.	Does the development of scientific knowledge require experiments? a) If yes, explain why. Give an example to defend your position. b) If no, explain why. Give an example to defend your position.	Empirical
4.	After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? a) If you believe that scientific theories do not change, explain why. Defend your answer with examples. b) If you believe that scientific theories do change: Explain why theories change. Explain why we bother to learn scientific theories. Defend your answer with examples.	Tentative Distinction between scientific theory and law
5.	Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.	Distinction between scientific theory and law
6.	Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?	Tentative Inferential Creative and Imaginative Distinction between scientific theory and law
7.	Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists used to determine what a species is?	Inferential
8.	It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypothesis formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?	Theory-laden

9.	Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced. a) If you believe that science reflects social and cultural values, explain why. Defend your answer with examples. b) If you believe that science is universal, explain why. Defend your answer with examples.	Social & Cultural
10.	Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations? a) If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate. b) If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.	Creative and Imaginative

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learner's conceptions of nature of science. *Journal of Research in Science Teaching*, 39(6), 497-521.

Appendix B

VNOS-C Questionnaire: Follow-up Interview Protocol

The follow-up interview protocol used in conjunction with the VNOS-C open-ended survey questionnaire included the following questions used by the interviewers as a guide (Related questions have been grouped together.):

1. What in your opinion is science?

2. How does science differ from other ways of knowing, such as philosophy or religion?

3. Why do theories change? (Or is new evidence/data the only reason theories ever change?)

4. What do you think comes first in scientific investigation, theory or observation?
    a. Why?
    b. Where did you learn these ideas?

5. Have scientists ever seen an atom?
    a. If so, how do they observe atoms?
    b. If not, how do they know what atoms know what atoms are like?
    c. Where did you learn these ideas?

6. Do scientific laws ever change?
    a. How would you rank scientific theories and laws in regard to importance?
    b. Can you give any examples of laws that have changed?
    c. Where did you learn these ideas?

7. What is the scientific method?
    a. Do all scientists use the scientific method when conducting investigations?
    b. Where does creativity fit in?
    c. Where did you learn these ideas?

8. How necessary are experiments in the development of scientific knowledge?
    a. Is any scientific knowledge developed without experiments?
    b. Where did you learn these ideas?

9. (Regarding responses of participants referring to instances when the participants believe a scientist's background influences the scientists' conclusions.) What do you mean by different backgrounds?
    a. How do these different backgrounds affect scientists' conclusions when they are looking at the same data?
    b. Is science simply a matter of interpretation? Is one person's view as good as the next?
    c. Is science subjective?
    d. Where did you learn these ideas?

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learner's conceptions of nature of science. *Journal of Research in Science Teaching*, 39(6), 497-521.

Appendix C

The VNOS-C Questionnaire Scoring Rubric

Empirical Aspect of NOS	
0	Does not articulate that observations of the natural world are a major criterion that sets science apart from other disciplines.
1	Uses terms such as concrete, study of physical thing, alludes to observations. But also describes science as “fact” or “proven” or with other inappropriate terms.
2	States the role of observation among other ideas (e.g. experiments) in the scientific process or mentions the idea of repeatability with experiments.
3	States scientific knowledge is based upon observation and stresses the repeatability of those observations. Clearly delineates scientific knowledge from religious or other types of knowledge.
Inferential Aspect of NOS	
0	Knowing is seeing, does not distinguish between observations and inference-making. Does not use the term “interpret”. “Facts speak for themselves”.
1	Speaks of interpreting, interpretations; but includes misconceptions such as “facts speak for themselves”, or “atoms are seen”, “can test what a species is”, etc.
2	Articulates the role of interpretation, inference in several responses. However term is limited primarily to use with a scientist’s “worldview” or “religious background”. Does not apply proper use of the term in context of constructs such as species or atoms.
3	Articulates distinction and relationship between observations and inferences consistently throughout responses and in the appropriate contexts.
Theory-laden Aspect of NOS	
0	Claims scientists are objective. Differences in views due to unclear data. Further discoveries or study will lead to one correct view or explanation of phenomena.
1	Articulates that different viewpoints of scientists may influence interpretations or views theory laden aspect in religious terms only; uses “bias” in a negative context or application; contains several contradictions in responses.
2	Consistent use of “bias” in a broad and neutral context when speaking of interpretations. Does not articulate educational, motivational, interest differences, etc. as reasons for different scientific views.
3	Articulates several differences including educational, motivational, interest differences, etc. as reasons for different scientific views. Responses are not contradictory.

Continued

Appendix C continued

Distinction between a Scientific Law and Scientific Theory	
0	Inappropriate description for both law and theory. Scientific theory not “set in stone”, it can change; a scientific law is “set in stone” and can change.
1	Properly describes either scientific law or scientific theory but not both. Includes misconceptions such a hierarchical relationship between the two.
2	Properly describes a scientific law and scientific theory but responses include contradictory statements and/or misconceptions.
3	Properly describes a scientific law and scientific theory. Contradictory statements and/or misconceptions are absent.

Social and Cultural Embeddedness Aspect of NOS	
0	There are no references to science influencing culture or culture influencing science. Science processes are seen as standing apart from culture, transcending culture.
1	Affirms culture and societal norms influence science but some responses are contradictory. Lack of examples indicates a limited understanding.
2	Affirms culture and societal norms influence science without contradictions but does not provide examples or elaboration.
3	Affirms culture and societal norms influence science without contradictions. Elaborates on the relationship with examples or elucidates the relationship in detail.

Tentative Aspect of NOS	
0	States science is “proven”; If there are repeated observations or experiments this will establish scientific facts, theories as absolute true or truth.
1.5	States some areas of science change (e.g. theories) but some do not or cannot (e.g. laws.) Contradictory statements are found in the responses. No mention is made of what can cause scientific ideas, principles, etc. to change.
3	States science is subject to change including theories and laws. Science cannot give absolute truth, only confidence. New data, new perspective on the data, cultural influences are listed as agents of change.

Creative and Imaginative Aspect of NOS	
0	Denies the use of creativity or imagination in science, considered as bias.
1.5	Creativity and imagination may be used but only in limited areas such as developing experiments or data collection techniques. Creativity and imagination are to be avoided in other areas such as data analysis.
3	Creativity and imagination are used throughout scientific endeavors including data analysis, research design, hypothesis forming and theory development.

Appendix D

Examples of Categorized and Scored Participant Responses to The VNOS-C Questionnaire

Empirical Aspect of NOS	
0	Um-- no. Um-- because you have to have facts along with what you find. You have to be able to classify it, and then analyzing it. I think it takes a lot of steps other than just interpretation. You have to have facts. I think that's your base for science. I think you'd have to get it, the information from multiple people. Um--so that way it's not just like your opinion because you may have missed something. [Participant 22]
1	Study of what make everything on earth go.. is different because it studies nature. … Everything like that's kind of like the basis of everything so I guess I'm saying that science is like the basis of like my shirt like you had to like my shirt just didn't appear like it was from…made up. [Participant 36]
2	Investigation of the world around us. The world can be described and explored and explained using only natural processes. I mean because with science you're using natural processes and everything around you to discover the truth. And with philosophy you could be using more of like arguments based on logic and um--other methods like that that aren't necessarily involving experimentation and um-- looking just at your specific set of data. … And so, I mean if you don't continue to do experiments and um-- go through the scientific method then you just might assume something's true I mean without it being true. [Participant 20]
3	Study of natural phenomena using repeatable methods, empirical data and logical reasoning…uses only natural reasons for explaining phenomena. empirical data on the existence of God. [Why can't creator as cause be tested] because you can't do tests that are repeatable to give evidence for its truthfulness. Usually what's held as good science is- is what is generally accepted by the majority of the scientific community and has been tested and experimented on and there have been repeatable evidences supporting the truthfulness of the held claims. [Participant 3]
Inferential Aspect of NOS	
0	I'm certain that they know the characterization of a species because they go by physical and behavioral patterns to group the species which is easy to see similarities in the different groups [Participant 30]
1	Scientists are pretty certain about this [what is a species]. Scientists can cross different kinds of dogs to get new breeds that can have offspring in the future. This is where a lot of like subjective and um creativity comes in, they obviously without being able to see it we don't know what the atoms look like, but Bohr and Dalton, John Dalton and all the people before them they would take the data they know and they would kind of through reasoning fill in the empty spaces so that they can create a model that follows the behaviors that they find through the experiments and the observations. [Participant 55]
2	Use evidence from genetic comparison, trait comparison and interbreeding capabilities to determine the range of a species. … likely to lead them to correct conclusions (given their definition of a species) Um-- like one scientist could have like a biological background and one could have like a geological background that could change how they think about the phenomena that they are observing in nature. Well like religious um-- definitely has a big impact on that like what type of religion you are will affect how you interpret that data and the effects of the presupposition of which are within the data. [Participant 3]
3	Bit more certain because the term species is a term created by humans. We defined it, so they are sure of it. Species is not a theory. They observed how organisms interact and then defined that a species would describe "a group of organisms that share similar characteristics and can interbreed" … I have coming from a different background than someone who has experienced different things and have different ideas that they are coming up with and using to interrupt the data that's being looked at. [Participant 16]

Theory-laden Aspect of NOS

0	The data is unclear so it leaves room for different possible theories. [Participant 38]
1	People have different views on conclusions. They may see different data in an entirely new way – not everyone sees the same things or they could want to outdo or outsmart the others. Well I never really thought about them being connected. I said up here science I just think of it as hands on. They just they work with it to--to interpret what is going on. [Participant 22]
2	Because there could have been two different groups of scientists that believe certain things. One group could have been a group of evolution theory scientists while other could have been a group of young earth scientists thus making them believe and conduct experiments in two different kinds of ways. I would say that some—some I would think that with an-- in the realm of science just how I would say yeah that some people's religious beliefs would change what they think about certain scientific things. [Participant 40]
3	Different conclusions are possible because both scientist groups looked at the data with their own set of assumptions. As humans it's impossible for us to interpret data without some bias, so in this case the scientists' bias and presuppositions swayed the way they perceived the data. Um---like the one scientist I believe talks about the meteorite, so he might have been more um--knowledgeable about astronomy and things like that. He might have had more of a space background before he came in to look at this data. Therefore he was thinking well this kind of connects with everything that I know about a meteor, so this might work. Whereas the other one, what does he say, he says…oh the volcanic eruptions. He might have more of a background in earth science and say well, you know, this could cause those same effects as well so, look there's some, you know, evidence that supports that so that's going to be my background. [Participant 20]

Distinction between a Scientific Law and Scientific Theory

0	We need to know [theories] the base of the pyramid before we can build to the peak. We want to improve upon others' experiments bust we can only do that if we learn the first discovery VNOS4 T is something that can never be proved – it is constantly changing due to new information we have gained. A law is something that will never change – it is true and has been supported over and over again. [Participant 21]
1	A law is a scientific principle that has been proven, through experimentation and the scientific process to be true… A theory, however is a theory. There is no real empirical data to prove a theory. Evolution… cannot be proved with empirical data. The law of gravity is proven daily and can be shown to be true by empirical data. The structure of an atom is based on the atomic theory. This means that the atomic structure has not been proven enough to be true to be a law. Ok a law is something that can be proven over and over again like the law of gravity. What goes up must come down. Like there is force acting on all objects that will--that will cause them to fall and like we're all affected by gravity. That is a law. That is something that we can see over and over again. Um-- a theory is something that you can't necessarily prove like the theory of well like of creation. [Participant 17]
2	Since they [theories] are not laws, and are just explanations, new evidences may be discovered which can alter the theory to fit the new information. Scientific law is something that can be directly observed and proven… Laws are made up of observations and supported hypotheses to the degree where it can actually called truth. A theory is the explanation of how something happened but it can never be proven. I know a theory is kind of like an explanation of um--why or how or some... Um--well a law I would say is something that um--um--is proven and it can be applied to anywhere in the universe, so because we have like the law of gravity here alright on a different galaxy or in the solar system everything has the law of gravity, everything has gravity. [Participant 9]

3	Scientific theories are valuable because they have been supported with a great deal of evidence. Scientific laws describe how things typically work in the natural world… just a description of what we see happening but now how or why it happens. Scientific theories attempt to explain how things actually happen. Theories are supported by huge amounts of observations and experiments. [Participant 19]

Social and Cultural Embeddedness Aspect of NOS

0	Science is universal – the periodic table of elements does not change based on culture, religion or values. [Participant 33]
1	I believe that science itself – theories, facts, laws, are above cultural and social values. However, whenever science is interpreted by humans, it will reflect the values of that person, culture, or society. Example medical technology – Western world use of medical science vs. eastern. [Participant 6]
2	I think that all things are affected by a person's culture and worldview. Take science for example. It is infused with ideals from the culture or view that a person has. [Participant 7]
3	Science is impacted by the society in which it is practiced… Second, society often dictates the direction of science, ie. What science can /can not investigate or what science will investigate. All scientists come to science with a priori assumptions and philosophical commitments rooted ina person's cultural identity and social upbringing. Scientists are never totally objective VNOS9 For example, cultural values about human life restrict research on human embryos and stem cells in the US, while different sets of values allow more free research on embryonic stem cells in Europe. [Participant 11]

Tentative Aspect of NOS

0	I believe they are very certain. They have done many experiments to validate their findings. … have high power microscopes so they can see the make-up of an atom. [Participant 29]
1.5	- Um-- new data would change like could change your therapy like they used to think that the earth was the center of the universe and then they had astrological discoveries that told them it wasn't and so the new data can change a theory even though theories are generally backed up by a lot of evidence. - I don't know. It seems that new data is the only thing that would have someone change their theory. [Participant 3]
3	-I think it's um--as as our society becomes better with technology and more sophisticated with technology it allows us to make better um--make better experiments, um--have more accurate results um--and being able to test those things. I mean back then they couldn't test they might not have been able to see microscopic things where as like now we can and um--so the better we get technology wise I think that's what is really driving the change in our information. Not necessarily but, in this example I think that's what happened. They were able to um--I don't know have more better equipment to make these things, but I mean also it's probably just other ideas coming in um--you know I'm sure with the plum pudding model the--the scientist who came up with that I mean I'm sure he was working with other people, too, but when other people like whoever came up with the solar system model probably had just different experiments or experiences and different ideas and so he brought that to the table and so other people and just what they know and what they have um--experienced in their experiments and what they've observed can change theories. [Participant 16]

Creative and Imaginative Aspect of NOS	
0	I do not think they use any creativity because they are usually only looking at facts and base everything on what they can see, hear, touch, smell, etc. Nothing is counted as evidence that is outside their senses and they will not usually take anything as truth if science could contradict it. [Participant 5]
1.5	Imagination and creativity play a large role in experiments, especially in the preliminary states. Scientists rely on those qualities to come up with things to test and explore. Scientists may also use creativity and imaginations to solve problems throughout the data collection process. When examining the data, scientists try to avoid these qualities as to keep bias and error from the results of the experiment. [Participant 10]
3	I believe that scientists use imagination and creativity in planning, designing, data collecting and after data collection in order to thoughtfully deal with and analyze information. All humans are designed with an innate ability to create and imagine – that is the root and foundation of exploring the natural human world. God designed us in his image to create and imagine. [Participant 25]