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Using an Explicit NOS Flow Map in Instruction of Nature of Science Based on the Science of Philosophy

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ABSTRACT

The purpose of this study is to develop a flow map for history of science instruction on nature of science (NOS) using a cognitive strategy. This is done to enhance overall scientific literacy through specificity and reflectiveness, and to examine pre-service elementary teachers' understanding of the NOS using NOS flow maps concerning Galileo's discovery of sunspots. There exists a general consensus in the science education literature regarding the goal of enhancing learners' views of the NOS. An extensive body of research in the field has highlighted the effectiveness of explicit NOS instructional approaches in improving learners' views on the NOS. Because it is valuable to introduce elementary students to some of the ideas developed by Kuhn, pre-service elementary teachers' understanding of the NOS was explored using an explicit NOS flow map developed as an instructional tool. The lessons combined cognitive conflict strategies in episodes concerning the history of science (Galileo's discovery of sunspots) with accompanying responses consisting of illustrations and questions. The lessons were designed to spend 50 minutes on study of the history of science, including conflict strategy, and 30 minutes on an explicit NOS flow map including all elements of the NOS. Students demonstrated understanding of tentativeness of scientific knowledge, and the lack of a universal scientific method. Therefore, instruction based on an NOS flow map is a promising method to enhance science teaching and learning.

Keywords: Cognitive strategy, Copernican Revolution, history of science, Kuhn's philosophy, nature of science.

INTRODUCTION

Scientific literacy requires an understanding the nature of science (NOS), the scientific enterprise, and the role of science in society and personal life (NRC, 1996, p. 21). Despite promotion of the potential benefits of NOS instruction and widespread endorsement by the science education community, research has consistently shown that K-16 students do not attain the desired comprehension (Lederman, 2007). Understanding the conceptions and beliefs of pre-service teachers (PSTs) about the NOS is important for improving the actions and activities developed in PST training courses (Colagrande, Martorano, & Arroio, 2016).

The history of science (HOS) approach employs episodes from scientific history to illustrate various aspects of the NOS. The implicit approach emphasizes doing science, assuming that participation in authentic scientific investigations will help students develop

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more accurate understanding of the nature of scientific inquiry and knowledge. The explicit approach specifies that instructional goals related to the NOS "should be planned for instead of being anticipated as a side effect or secondary product" (Akindehin, 1988, p.73)

Abd-El-Khalick and Lederman (2000a) emphasize the following:

> The relative ineffectiveness of the implicit approach could be attributed to two inherent assumptions. **The first** is that attaining an understanding of NOS is taken to be a ***cognitive* learning outcome**. **The second** ensuing assumption is that learners would *necessarily* develop understandings of NOS as a by-product of engaging in science-related activities. They should be able to use examples and/or ***simplified case histories*** from scientific practice to substantiate this claim and make it accessible and understandable to students. (p. 665)

Using HOS as a context for science instruction provides students with more opportunities for reflection, discussion, and deep critical thinking. Further, teachers without the requisite understanding of the NOS are likely to promote absolute views, the knowledge aspects of science (Gess-Newsome, 1999). These science educators ignore the role of creative ideas in the production of science knowledge (Duschl, 1990), and may hinder students in developing the correct perspective on science. To overcome this, Bell, Matkins, and Gansneder (2011) have claimed that understanding of the NOS could be improved by introducing argumentation, and more recently, Bakırcı, Çalık, and Çepni (2017) claim that understanding of the NOS could be based on the Common Knowledge Construction Model (CKCM). However, because HOS can directly show the impact of scientific knowledge on culture and society at a certain time (Solomon, Duveen, Scott, & McCarthy, 1992), it can effectively illustrate the scientific research process.

In contrast to reports of the positive effect of HOS instruction on understanding the NOS, some cases with almost no effect have also been reported (Abd-El-Khalick & Lederman, 2000a; Tao, 2003). HOS is presented in the form of data records or lectures in classes with HOS as its subject matter. However, the students in general tend to comprehend the historical information in terms of their own perspective, without regard for the historical standpoint—in other words, the contemporary social state or worldview (Abd-El-Khalick & Lederman, 2000a). Therefore, mere introduction of HOS to NOS instruction does not guarantee students' understanding of the NOS. It is necessary to develop a tool for explicit NOS instruction that not only directly incorporates the research efforts of scientists and the social and cultural impacts to the historical context, but also functions as a bridge to the modern history of science. In short, the NOS must be made explicit within historical case studies.

Scientific literacy encompasses an understanding of both science content knowledge (SCK) and the NOS. School science, however, tends to focus only on teaching SCK, often ignoring the NOS (Clough, 2006). Many students' ideas parallel early historical scientific ideas, suggesting that "alternative conceptions" may sometimes be a better descriptor than "misconceptions." Classical Conceptual Change Theory arose from both Piaget's theories of children's thinking and Kuhn's HOS work (referred to in this study as "case studies"), as well as work in science education on students' and teachers' preconceptions (Oh, Lee, & Lee, 2017; Zohar & Aharon-Kravetsky, 2005; Torres, Moutinho, & Vasconcelos, 2015).

Cognitive conflict has been considered an important factor in learning since the days of Piaget. He believed that when children's interactions with the world result in experiences that do not fit their current conceptions, their mental balance is disturbed (i.e., a cognitive conflict occurs). Cawthron and Rowell (1978) drew parallels between Kuhn's findings and Piaget's theory of knowledge and psychological account of constructive knowing.

Naturally, there are constraints on what can be achieved in terms of affecting elementary teachers' conceptions of the NOS in the context of science methods courses. These include time constraints, the extended agendas of the courses, and elementary teachers' limited knowledge of science content and experience with science (Akerson, Morrison, & McDuffie, 2005; Morrison, Raab, & Ingram, 2009). Abd-El-Khalick and Akerson (2004) found that an explicit-reflective approach to instruction was even more effective in improving elementary teachers' views of the NOS when undertaken within an orthodox conceptual change model (CCM) framework of learning (Hewson, Beeth, & Thorley, 1998; Posner, Strike, Hewson, & Gertzog, 1982).

In this study, we consider how the NOS has relates to the philosophy of Kuhn. We then identify the ways in which a historical science case (a science study) can embody the key elements of the NOS, suggest the instructional sequence for an explicit NOS flow map as a *cognitive resolution*, and examine PSTs' views of the NOS using the case of Galileo's discovery of sunspots, an example of the Copernican Revolution.

BACKGROUND

An explicit NOS flow map for aspects of the NOS through the new philosophy and conceptual change model

According to Eflin, Glennan, and Reisch (1999),

> It is valuable to introduce students at an elementary level to some of the ideas developed by Kuhn. In particular, students benefit by considering the idea that different paradigms compete with each other, and that they can easily understand some of the ways in which theoretical commitments and social issues can influence the development of science. On the other hand, students should be made aware that some interpretations of Kuhn's views are extreme and not persuasive (radical incommensurability). (p. 114)

Thus, even if we are unwilling to accept Kuhn's incommensurability thesis, we should recognize that learners should make a genuine effort and extended commitment to achieve the conceptual shift necessary to make the historical approach useful for science learning (Abd-El-Khalick & Lederman, 2000b).

The middle-of-the-road approach is suggested by some of the NOS tenets given in American Association for the Advancement of Science (AAAS) reports. Regarding this middle-of-the-road approach to Kuhn's works, Loving and Cobern (2000) state the following:

> An important portrait of Kuhnian works about the nature of science deals with the theory-ladenness of observations. The notion of the theory-ladenness of observations in science is one of the least controversial aspects of current views of the nature of science. The degree of interference and the extent to which interpretations of observations are controlled by existing knowledge varies in writings from the extremes of Feyerabend to Toulmin to the relatively conservative acknowledgements of Shapere and Laudan, Kuhn is somewhere in the middle on this continuum, but his widely read *SSR* probably serves as a primary source of support for most on this issue. (p. 190)

Despite continuing disagreement on a single definition for the NOS, at a certain level of generality and within a certain time period, wisdom about the NOS is shared. Considering issues related to student accessibility, public recognition, and usefulness to citizens, Lederman (2007) has proposed the following:

> Seven key aspects of NOS: Scientific knowledge is **tentative** (subject to change), **empirically** based (based on and/or derived from observations of the natural world), and **subjective** (involves the personal background, biases, and/or is **theory-laden**); necessary involves human inference, imagination, and **creativity** (involves the invention of explanations); and is **socially and cultural** embedded. Two additional important aspects are the distinction between **observation and inferences**, and the functions of and relationships **between theories and laws**. (p. 53)

We insist that none of these aspects should be considered independently of the others. Thus, these key aspects of the NOS are viewed in this study as interdependent, dynamic, explicit, and reflective (see Figure 1). Empiricists argue that our human perceptions give us objective facts about the world that form the foundations of science; general laws and theories are inductively produced based on those facts. However, human perception is not objective. Judgments and inferences on observable facts in specific situations vary depending on the person, the culture, and the theoretical school.

That is, with respect to social and cultural background and the social dimension, perception is formed and developed in a decisive manner by the subjectivity of observers: their cultural and theoretical background, their expectations, and their perspectives. This consideration falls under "the theory-ladenness of observation" in the philosophy of science. Additionally, empiricists say that law, which demonstrates regularity, and theory, which requires creativity, should be separated. Because of the theory-ladenness of observation, we insist that law and theory should be dynamic rather than distinct from one another. Similarly, most modern philosophers of science have questioned the hierarchical/dichotomous relationship between laws and theories (Giere, 1999; Niaz & Maza, 2011, p. 5). The development of scientific knowledge involves making observations of nature. That is, observations are not "scientific methods" represented by induction. Finally, because an objective law or theory is not produced from objective facts, a scientific theory is, indeed, *tentative*.

The lack of consensus over fundamentals distinguishes mature, "normal" science from the relatively disorganized immature pre-science. According to Kuhn, immature pre-science is characterized by total disagreement and constant debate over fundamentals. There will be almost as many theories as there are workers in the field.

The disorganized and diverse activity that precedes normal science eventually gains structure and direction when a single paradigm emerges, adhered to by the scientific community. Kuhn describes formal science as "puzzle-solving," because problems are solved within the terms of the paradigm. With respect to a paradigm, an unsolved problem is simply an anomaly, fodder for future researchers. In periods of normal science, the paradigm is not open to serious question. Nothing good lasts forever, however, and that includes normal science. Anomalies accumulate, and may eventually be seen as real problems rather than mere puzzles. Kuhn terms this "a period of crisis" (Sismondo, 2004, p. 13).

If an alternative is presented that solves some of the accepted paradigm's central unsolved questions (for example, experimentation yields a new paradigm candidate, and the *seriousness of a crisis deepens*), then some scientists, particularly younger scientists who have not yet been fully indoctrinated into the beliefs and way of life of the older paradigm, will adopt the alternative. Eventually, a robust alternative may become a paradigm itself, structuring a new period of normal science through paradigm shift, or extraordinary or revolutionary science.

In *The Essential Tension* (Kuhn, 1977), Kuhn discusses the relations of cognitive structures and learning conditions for learning of scientific knowledge. It was important components in establishment of a paradigm in which learning, cognitive apprenticeships, and transmission of basic concepts and methodologies were.

Classical conceptual change theory arose from Piaget's theories of children's thinking and Kuhn's history of science work. The Piaget theory of the development of cognitive structure ("Kuhn's paradigm") suggested that disequilibrium or cognitive dissonance with respect to the initial conception must be created within an individual to facilitate learning (Rea-Ramirez, Clement, & Nŭňez-Oviedo, 2008, p. 24).

Cawthron and Rowell (1978, p. 46) first linked Kuhn's ideas on the noncumulative, discontinuous grow of scientific knowledge with Piaget's views of the staged development of individual cognition.

Thus, both the worldview and the developmental level of an individual are determined by a dialectic process whereby a dynamic equilibrium is nonstatic, and new cognitive structures evolve through the dialectic process (known as "equilibration" in Piagetian terms).

An explicit approach might not suffice to substantially change students' entrenched conceptions of the NOS. An orthodox conceptual change model approach (Posner et al., 1982; Oh, 2017; Abd-El-Khalick & Akerson, 2004) might be more effective, as suggested by Abd-El-Khalick and Lederman (2000b):

> Students' views of certain NOS aspects are first elicited. Next, specific historical examples are used to help students discern the inadequacy of, and raise their dissatisfaction with some of their current NOS conceptions. Students are then explicitly presented with more adequate conceptions of Target NOS aspects. The historical narrative (cases) can then be employed to provide students with opportunities to perceive the applicability and fruitfulness of these newly articulated views in making sense of various aspects of scientific knowledge and practice in a variety of historical and disciplinary. (p. 1089)

The CCM also assumes that "ontogenetic change in an individual's learning is analogous to the nature of change in scientific paradigms that is proposed by philosophers of science" (Pintrich et al., 1993, p. 169). Conditions necessary for conceptual change to occur are dissatisfaction with existing conceptions, intelligibility of a new competing conception, plausibility, and fruitfulness. Posner et al. imply that in raising the status of a new conception, the above conditions will be fulfilled in a linear fashion, starting with dissatisfaction with the existing scientific conception and proceeding to the new conception's fruitfulness (Tyson et al., 1997).

In Figure 1, the dark orange section, "social and cultural effects," relates to *dissatisfaction*; the "subjective" light orange section, which describes certain scientific activities, relates to *intelligibility*; the remaining light orange sections, describing scientific activities, and the yellow sections, describing the scientific products of these activities, relate to the *plausibility* and *fruitfulness* of a suggested concept. The white section describes the overall result of these conditions: the tentativeness of scientific knowledge, turn out through dissatisfaction, specifically social and cultural pressure.

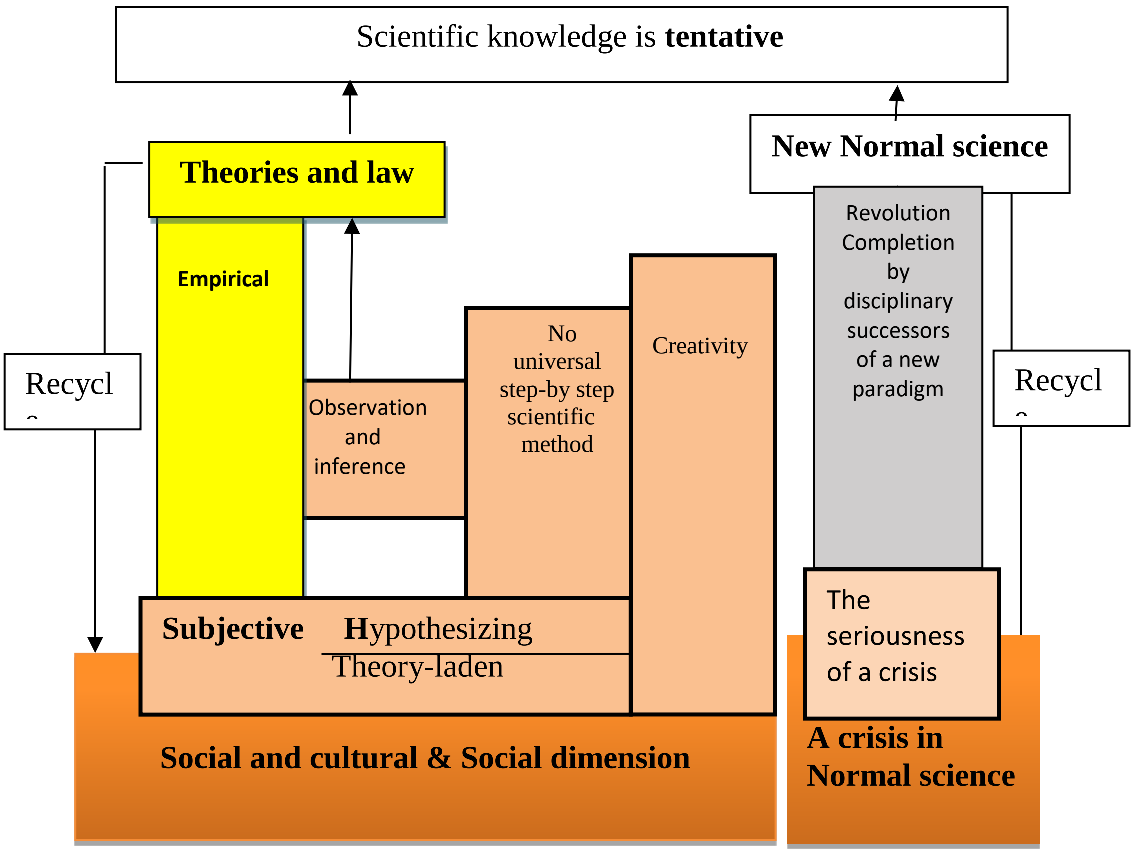

Figure 1. *Relationship between NOS and Kuhn's Scientific Revolution (Modified from Oh, 2017)*

Generation of cognitive conflict: dissatisfaction with existing conceptions

A crisis in normal science arises due to a number of serious anomalies. (The social and cultural embeddedness of scientific knowledge and the crisis of Kuhn's normal science.) Science as a human enterprise is practiced within a larger cultural context, and its practitioners are products of that culture. Thus, it follows that science affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Therefore, anomalies are regarded as *serious* if they are important with respect to some pressing social need. Also affecting the seriousness of an anomaly is the length of time it resists attempts to remove it (Chalmers, 1990, p. 113).

Resolution of cognitive conflict: intelligibility of the new competing conception, plausibility, and fruitfulness

The seriousness of a crisis deepens due to the appearance of an alternative. (Subjective: The theory-laden nature of scientific knowledge and the seriousness of Kuhn's normal science crisis.) Observations (and investigations) are always motivated and guided by questions or problems, and they acquire meaning with reference to these questions or problems, which are derived from certain theoretical perspectives (Lederman et al., 2002). According to Kuhn, a new paradigm, or a sufficient hint to permit the articulation of a new paradigm, emerges suddenly, sometimes in the middle of the night, in the mind of a man deeply immersed in crisis (Chalmers, 1990, p. 114).

Revolution by disciplinary successors of a new paradigm

Through the continuous study of disciplinary successors, additional empirical observations accumulate to resolve serious anomalies, and through the new observations and inferences developed to explain them, new laws and theories are generated.

Observations are descriptive statements about natural phenomena that are directly accessible to the senses (or extensions of the senses), and about which observers can reach consensus with relative ease. By contrast, **inferences** are statements about phenomena that are not directly accessible to the senses (Hull, 1998, p. 146).

Scientists derive specific, testable predictions from theories and check them against tangible data. Closely related to the distinction between observation and inference is the distinction between scientific theories and laws. In general, laws are descriptive statements of relationships among observable phenomena. Theories and laws are different kinds of knowledge, and one does not become the other. However, we insist that laws (which demonstrate regularity), like theory, are a function of human creativity and should be considered in a dynamic rather than separate way because of the theory-ladenness of observation. As Niaz and Maza (2011) state:

> Researchers in current science education also questioned the dichotomy between theories and laws (McComas et al. 1998). Scientific progress is characterized by a series of theories or models (plausible explanations), which vary in the degree to which they explain/interpret/predict the experimental findings. (p. 5)

According to Kuhn's philosophy, which recognizes the theory-ladenness of observation, the relationships between the empirical facts involving anomalies, inferences, and scientific theories are dynamic rather than linear. As Brown (1977) states:

> Only after Researcher has learned to see reality in terms of acceptable theory is research possible, but it is also possible for the researcher to discover anomalies and thus come to reconsider acceptable theories … Theories often provide a definite description of what the scientist ought to see and thus sharpen his vision for the discovery of anomalies. And as long as the scientist is carrying on empirical investigation it is not theory alone which determines what will actually occur, but theory in conjunction with a theory-independent world … It is the recalcitrant anomalies that eventually lead to the overthrow of one theory and its replacement by another… (pp. 108-–109).

The development of scientific knowledge involves making observations of nature. Nevertheless, generating scientific knowledge also involves human imagination and creativity (Lederman et al., 2002). Creativity is necessary for all inquiry procedures, based on all key aspects of the NOS. One of the most widely held misconceptions about science is the existence of a scientific method. There is *no single scientific method* that guarantees the development of infallible knowledge (AAAS, 1993; NRC, 1996).

Factors such as Kuhn's scientific revolutions involve a change, not just in the range of claims made but also in the kinds of entities (theories) that are assumed to constitute the world and the kinds of evidence and modes of explanation that are deemed appropriate. Such changes arise through a great deal of creativity on the part of disciplinary successors of a new paradigm.

A new stage of normal science and its recycling (expansion)

After a scientific revolution by disciplinary successors is completed, a new paradigm emerges. Scientific knowledge, although reliable and durable, is never absolute or certain. This knowledge, including facts, theories, and laws, is subject to change. Scientific claims change as new evidence, made possible through advances in thinking and technology, is brought to light, and as extant evidence is reinterpreted in light of new theoretical advances, changes in cultural and social spheres, or shifts in the direction of established research programs.

Tentativeness in science does not arise solely from the fact that scientific knowledge is inferential, creative, and socially and culturally embedded.

Because the flow map we developed is closely connected to Kuhn's scientific revolution (cognitive resolution and the history of science), we must discuss the relations between our flow map and the elements of NOS and Kuhn's philosophy (see Figure 1).

Although consensus about the NOS may be generally established, the meaning of the "sophisticated" Views of Nature of Science (VNOS) items remains debatable. However, the VNOS items are not to be taken in isolation. When examined holistically, they provide powerful insight into responden conceptions, especially when examining students' responses across VNOS-C items, contexts, and science-based scenarios (Schwartz, Lederman, & Abd-El-Khalick, 2012).

Table 1. *The other views about the elements of NOS*

Scientific Literacy (Zeitler & Barufaldi, 1988)	The elements of NOS		
	Skill	Attitude	Knowledge
Inter-relationship NOS (Oh, 2017)	No scientific methods, observation & inference (theory – dependence, creativity)	Social dimension & Social and Cultural effects, (theory – dependence, creativity)	Scientific knowledge, Empirical
Kuhn's Philosophy and History of Science	The seriousness of a crisis & Revolution Completion by disciplinary successors of a new paradigm	A crisis in Normal science	Revolution Completion by disciplinary successors of a new paradigm

Zeitler and Barufaldi (1988) encourage educators to use experiences of scientific enquiry, scientific attitudes, and basic scientific knowledge in teaching, all of which are integrated as scientific literacy. Therefore, it is necessary to present the NOS as a combination of these three elements in this study as well. Attitudes about science can have a significant effect on scientific literacy. In education theory, understanding of content lies in the cognitive domain, while attitudes lie in the affective domain. According to Flick (1993), there are three major dimensions of learning in science: knowledge, skills, and attitudes.

Within the field of science education, there has been sustained interest in better preparing students to engage in discourse and decisions concerning societal dilemmas and controversies, first in the area of science-technology-society (STS) instruction (Solomon & Aikenhead, 1994) and more recently in relation to the socio-scientific issues (SSI) movement (Sadler, 2011; Zeidler, Sadler, Simmons, & Howes, 2005). SSI research has traditionally focused on individual decision-making (Bencze & Alsop, 2014), aiming to develop responsible citizens capable of applying scientific knowledge and habits of mind such as skepticism, open-mindedness, critical thinking, recognition of multiple forms of inquiry, acceptance of ambiguity, and search for data-driven knowledge (Zeidler, Osborne, Erduran, Simon, & Monk, 2003). Thus, according to Oh (2017), the following terms can be used to describe the attitude, skill, and knowledge factors of science learning: **Scientific attitudes** refer to the social dimension, social and cultural changes, and subjectivity (theory-ladenness). **Scientific skills** refer not to specific scientific methods but rather to imagination and creativity, observation and inference, and subjectivity (hypothesizing). **Scientific knowledge** refers to laws and theories, and the elements of the NOS necessary to achieve wider scientific literacy (see Figure 1). In particular, subjectivity consists of hypothesizing (*skills*; AAAS, 1993) and theory-ladenness (*attitudes*; Martin, 2012).

Historical case studies: the NOS flow map for establishment of Copernicus's heliocentric hypothesis

Because Kuhn examined this episode in detail in his earlier book on the Copernican revolution (1962, pp. 139-140), he could confidently use it to support his theory of revolutions.

Cognitive conflicts

Crisis in normal science due to number of serious anomalies (the crisis of Ptolemy's geocentric model). For some time, astronomers had every reason to suppose that their attempts would be as successful as those that led to Ptolemy's model. Astronomers were invariably able to eliminate a given discrepancy by making an adjustment to Ptolemy's system of compounded circles. As time went on, however, a person looking at the net result of so many astronomers' research could observe that complexity was increasing far more rapidly than accuracy.

Kuhn's revolution begins with social and cultural pressure. The crises are regarded as serious with respect to some pressing social need. The problems with Ptolemaic geocentric astronomy were pressing with respect to the need for calendar reform in Copernicus's time, and during the Renaissance, Cosmos is a simple geometric model that Neoplatonism does not comply with the increasing number of unnatural epicycles (Chalmers, 1990, p. 113). Above all, the scientific knowledge of the Renaissance period involved reasonable explanations for obvious movements and experience. The system was nothing more than explanations appropriate to experience. *<Socio-cultural pressure and the social dimension>*

Resolution of cognitive conflict

The seriousness of a crisis deepens due to the appearance of an alternative (the appearance of Copernicus's system, an alternative for Ptolemy's system). After repeated examination of old data and lengthy contemplation, Copernicus suggested that placing the sun in the center of the universe would allow for a simpler depiction of planetary motion. Upon consideration, where else would be a better place for a sun that illuminates the universe than in the universe's center (Vigoureux, 2003, p. 86)?

Although a crisis of paradigm is realized by socio-cultural pressure, and the problem is partially solved by submission of new alternatives, new problems are introduced by a new paradigm. Disciplinary successors in a new paradigm arise as new alternatives emerge, and the old paradigm feels the severity of the crisis. In other words, study to solve new problems begins. Subjective and theory-dependent empirical data are identified as the new study direction for a new paradigm.

One of Kuhn's propositions about the NOS is the "theory-ladenness of observations." This thesis asserts that existing conceptions affect our perspective of the world around us (Loving & Cobern, 2000). In ancient Greece, Aristarchus suggested that the earth may rotate about an axis and revolve in an orbit around the sun. Almost 2000 years later, Copernicus also made this conclusion, presenting a system of the universe based on a combination of the earth's two motions about the sun to explain the retrograde motions of planets without the epicycles suggested by Ptolemy (Cohen, 1985, p. 45).

The Copernican system has more problems in an observational sense than the Ptolemaic system, because it was accepted that celestial bodies, based on Aristotle's ideas, demonstrated uniform circular motion, called "natural motion." However, the system strongly attracted disciplinary successors such as Galileo, Kepler, and Newton due to its "beauty." In other words, relative to the Neoplatonic philosophy popular at their time, which emphasized a simpler and beautiful sense (qualitatively simple and harmonious), the Ptolemaic system's explanations grew more and more complicated *<Subjective and hypothesizing >.*

Revolution by disciplinary successors of a new paradigm

The two rival systems were more or less equivalent with respect to simplicity and accord with observations of planetary positions. Nevertheless, a number of mathematically capable natural philosophers (Galileo, Kepler, and Newton) were attracted to the Copernican system. With Kepler, the Copernican revolution nearly reached “completion”; Kuhn identifies its final completion in Newton’s system (Sharrock & Read, 2002, p. 79). “Bringing together mathematicians and natural philosophers was a fundamental shift, one that involved social changes as well as intellectual ones. Over a hundred years went by before Newton fused their two approaches together in his book on gravity, making astronomy a mathematical science that aimed both to describe and to explain the cosmos” (Fara, 2009, p. 111).

“Opposition to Copernicanism did not simply collapse, but persisted, and only gradually faded away over the 150 years after the dearth of Galileo in 1642” (Sharrock & Read, 2002, p. 80). The main attraction of the Copernican hypothesis was how clearly it explained a number of features of planetary motion, which the rival Ptolemaic theory could explain only in an unattractive, artificial way.

The necessary reliance of science on empirical evidence distinguishes it from other disciplines, such as philosophy and social science. Its empirical basis is the aspect that we most easily understand. This is because we have significant concrete experience that evidence and experiments are important in science.

Although existing evidence is explained by a new theory, new evidence is also inferred and predicted. Galileo continued his studies, and in a mathematical abstraction he refuted the tower argument (which had been presented as counterevidence against the earth’s rotation) through an argument for stellar parallax (which was difficult to observe because of the great distance), based on his prediction that observations made not by the naked eye but by telescope would see stars behave identically, unlike planets. Ultimately, he presented some data supporting the heliocentric theory based on the phase changes of Venus *<Empirical Evidence>*. This example illustrates that scientific knowledge is based on empirical evidence, which is in turn based on inferred and predicted observations.

Later, based on the observations of Tycho, Kepler solved the problem of epicycles with his claim that a planet’s orbit was elliptical rather than circular. Kepler’s inference is most significant. He could not identify an elliptical orbit directly from Tycho’s data; instead, he explained Tycho’s observations by arriving at the conclusion of an elliptical orbit through an intermediate form from an initial circular orbit model.

An accurate picture of an elliptical orbit is difficult to obtain through observation. Although an accurate elliptical orbit only revolves when there is only one planet with the sun of infinite mass. Thus, abstract inference work is required. Rather than relying on empirical data from simple observations, it is absolutely necessary for scientists to use creativity in inference. This is because not only is observational data interpreted by inference, but inference forms the foundation for evaluating and predicting other observational data *<Empirical Evidence> through <Observations and Inferences>*.

The so-called “hierarchy of credibility” found in most science textbooks presents categories of scientific knowledge (i.e., observations, hypotheses, theories, laws/principles) in ascending order of credibility or certainty. Individuals often hold the simplistic, hierarchical view such lists present of the relationship between theories and laws—that is, that theories become laws as supporting evidence is accumulated over the years. It follows from this notion that scientific laws have a higher level of credibility than scientific theories.

This common belief about the relationship of theories and laws is inappropriate because, among other reasons, theories and laws are different kinds of knowledge, and one cannot develop or be transformed into the other. Laws are **statements or descriptions of relationships** among observable phenomena. Theories, by contrast, are **inferred explanations** for observable phenomena.

Usually, scientists do not formulate theories in the hope that one day they will acquire the status of "law." Scientific theories in their own right serve important roles, such as guiding investigations and generating new research problems, in addition to explaining relatively huge sets of seemingly unrelated observations in more than one field of investigation. For example, kinetic molecular theory serves to explain phenomena related to changes in physical states of matter, rates of chemical reactions, and heat and its transfer, to mention just a few.

Newton constructed the theory of gravity to explain Galileo's law of falling (based on a natural phenomenon) and Kepler's empirical law of an elliptical orbit, showing that a planet's revolution had a causal mechanism rather than a teleological cause, as suggested by Aristotle. Newton first constructed a law of gravity, then used Kepler's law to justify his theory. Therefore, laws and theories are have mutually dynamic but different roots, rather than a hierarchical order. <*Law and Theory*>**.**

The development of scientific knowledge is based on human imagination and creativity. Scientific knowledge is not simply a product of logic and rationality. There is no single "scientific method" a scientist must follow to produce scientific knowledge (AAAS, 1993; NRC, 1996; Shapin, 1996).

Individual disciplinary successors do not construct laws or theories simply through logical induction from collected data; creative work and insight are required to solve problems <*No Single Scientific Method*>, <*Individual Creativity*>.

Galileo's and Kepler's theories certainly enhanced Copernicus's theory. However, Copernicus's theory for comprehensive physics required more development. Newton replaced Galileo's law of circular inertia with the law of linear inertia. Of course, Newton's significant contribution is his theory of universal gravitation. With this theory, Newton could explain that Kepler's laws of planetary motion and Galileo's law of falling were correct < *theories and laws* >.

"It was Galileo's contemporary, Kepler, who contributed a major breakthrough in that direction when he discovered that each planetary orbit could be represented by a single ellipse, with the sun at one focus. This eliminated the complex system of epicycles that both Copernicus and Ptolemy had found necessary" (Chalmers, 1990, p. 100). Although the parallax-distance relation is a very simple mathematical formula, obtaining a value to use in the formula is very difficult, because the angle by which the star shifts is extremely small. It was not until the 1980s that the first parallax was measured by German astronomer Friedrich Bessel at Königsberg Observatory (now in Kaliningrad).

A new stage of normal science and its recycling: the expansion of normal science

> Galileo and Kepler certainly strengthened the case in favor of the Copernican theory. However, more developments were necessary before that theory was securely based on a comprehensive physics. Newton was able to take advantage of the work of Galileo, Kepler and others to construct that comprehensive physics. Once Newton's physics had been constituted, it was possible to apply it in detail to astronomy, fluid mechanisms and other domains. (Chalmers, 1982, p. 74)

New normal science: updating

Continuously expanded Newtonian models were applied to fluid mechanisms and other domains. Astronomers have long known that the major axis of Mercury's orbit does not remain fixed in space in relation to the stars. The major axis rotates around in the plane of the orbit. Part of this shift arises from the gravitational attraction of the other planets. When this and other effects are taken into account, there nonetheless remains a residual shift of 41 arcsec per century.

Is there perhaps an undiscovered planet, sometimes called Vulcan, orbiting within Mercury's orbit (Newtonian model's auxiliary hypothesis)? No such planet has ever been definitively observed (observation unexpected by Newtonian theory).

Recycling: retiring or revising Newton's theory

General relativity predicts motion influenced by the strong curvature of space-time close to the sun. Because the observed and predicted results of Mercury's rotation coincide to within a few percentage points, observations confirm general relativity.

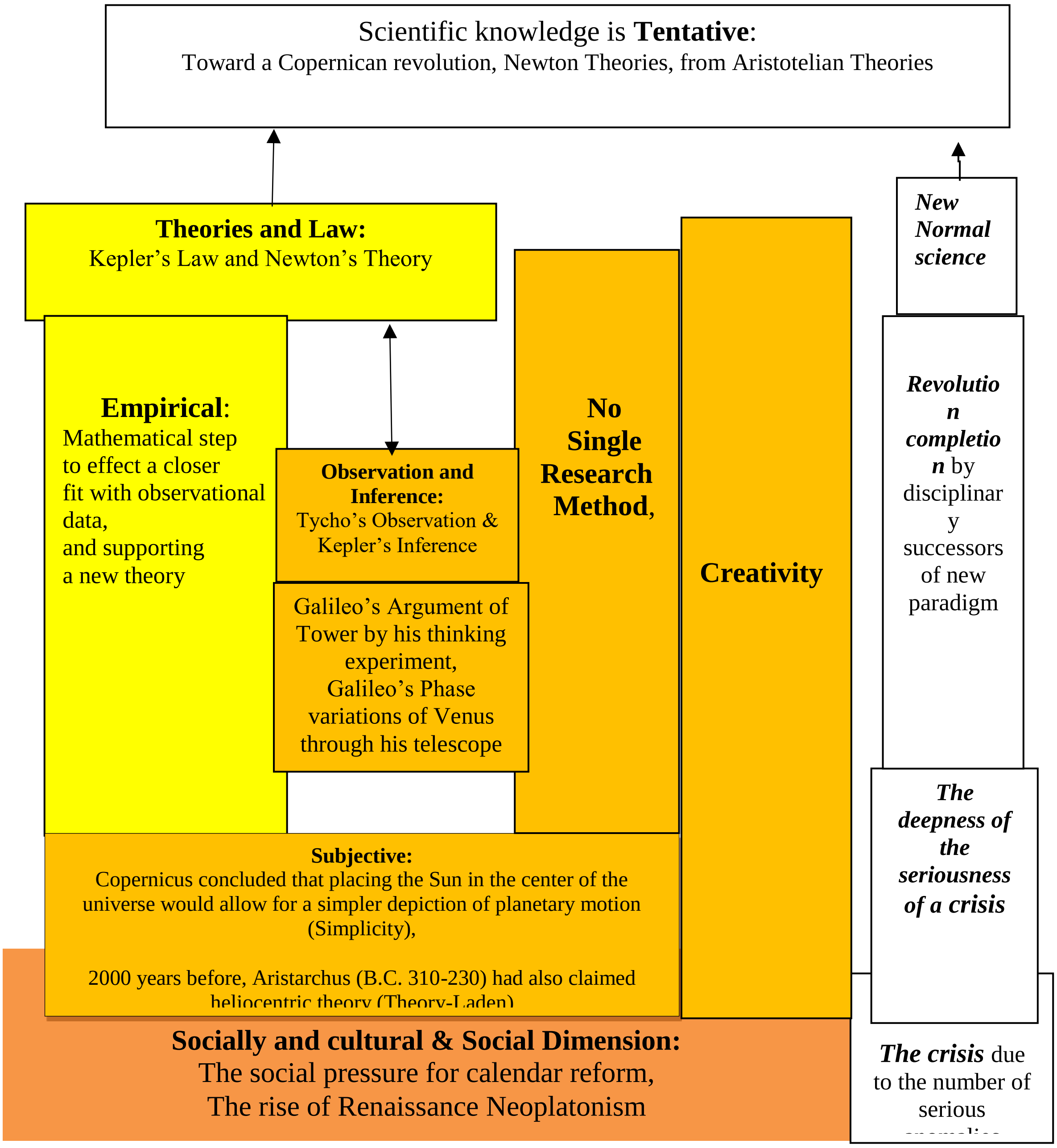

Figure 2. *The Copernican revolution: The Flow Map of the Nature of Science (NOS)*

METHOD AND PROCEDURE

Participants

The research subjects were 100 second-year pre-service elementary teachers enrolled in the Earth Science course for elementary science education in the fall term of the 2013-2014 academic year. They were selected based on their respective agreement to participate in S. N.

University of Education, located in Seoul, South Korea. The class was conducted by two professors and one Masters graduate student; two professors and one Masters graduate student conducted the research analysis. In this study, the experimental group (HOS with conceptual change model based on a developed NOS flow map; 50 students) and the HOS group without cognitive conflicts (50 students) were selected separately, with the assumption that pre-service elementary teachers' views of the NOS could not easily be changed by HOS methods alone, without cognitive conflicts.

Teaching the NOS: application of Galileo's historic investigation of sunspots with CCM based on NOS flow map

The sun was considered a symbol of perfection in traditional cosmology, but Galileo confirmed that the sun had spots, and asserted that it was not perfect. Although others had discovered these spots in the past, they were believed to be caused by the sun's moons passing in front of it, rather than spots on the sun's body itself.

> … many of these spots are seen to originate in the middle of the solar disc, and likewise many dissolve and vanish far from the edge of the sun, a necessary argument that they must be generated and dissolved. For without generation and corruption, they could appear there only by way of local motion, and they all ought to enter and leave by the very edge. (Galilei, 1967, p. 54)

Galileo asserted that sunspot groups appear to pass across the sun because the sun rotates. He based this assertion on observations of sunspot groups that he made on June 10 and June 11, 1612 (Hoskin, 1997, p. 128). Based on continuous observations, he found that the rotation period of the sun did not exceed a month (Fraknoi, Morrison, & Wolff, 1997, p. 295). Ultimately, Galileo's record of the apparent movement of sunspots proved that the sun rotates. In a famous passage from his *Dialogue Concerning the Two Chief World Systems*, Galileo states the following through the character Salviati, who serves as his mouthpiece:

> … The other observation, …, is that from the changes of shape observed in the spots, and from their apparent changes in velocity, one must infer that the spots are in contact with the sun's body… (Galilei, 1967, p. 54)

Scientists later showed that the rotation period of the sunspots differed depending on latitude, and that their maxima had an average interval of 11.1 years.

This phenomenon can be explained by the sun's magnetic field. The strong magnetic fields of the sunspots interfere with the flow of gas, by which thermal energy within the sun is delivered to the surface in currents. Due to this interference, areas with strong magnetic fields deliver less thermal energy. Therefore, areas with strong magnetic fields have a lower temperature, and are observed as dark spots (Fraknoi et al., 1997, pp. 296-297).

Sequence for use of NOS flow map: focusing on Galileo's sunspot discovery process

The class was conducted using the process by which Galileo discovered sunspots on the sun's surface and how it supported Copernicus's heliocentric hypothesis. Cognitive conflicts were resolved through reference to events in scientific history (see Oh, 2011). Although it was conducted in an orderly way by social and cultural pressure as anomalies, it was also conducted for these conflicts resolution as implicit NOS (HOS) at the first stage, and then an explicit NOS presentation (NOS flow map) at the last stage, as shown in Figure 4.

In other words, not every science process, skills instructional sequence, or scientific inquiry activity is an implicit attempt to enhance learners' conceptions of the NOS, nor is every instructional sequence in HOS an explicit attempt to achieve that end. The basic difference between implicit and explicit approaches lies in the extent to which learners are helped to grasp the conceptual tools—in this case specific aspects of the NOS—that enable them to think about and reflect on the activities in which they are engaged (Abd-El-Khalick & Lederman, 2000b).

Thus, HOS is focused on an implicit NOS approach to instruction, using cognitive conflicts inherent only in scientific history rather than suggesting the elements of the NOS. In contrast, an explicit NOS approach to instruction presents a dynamic change, with the HOS topic focused on instruction of an NOS flow map developed and suggested as a lecture tool by this study.

Pre-service elementary teachers' understanding of the NOS was explored through an explicit NOS flow map developed as an NOS instructional tool. The lessons combined cognitive conflict strategies in HOS episodes (Galileo's discovery of sunspots) with accompanying responses consisting of illustrations and questions. The experimental group's lessons were designed to include 50 minutes devoted to HOS, including conflict strategy, and 30 minutes to an explicit NOS flow map including all elements of the NOS. The HOS only group's lessons were designed to include 50 minutes only, devoted to HOS and including conflict strategy, as shown in Figure 3.

First Stage: History of Science (HOS)

Instruction in the HOS group was completed without the cognitive conflicts of the CCM.

Understanding students' preconceptions.

The teacher assumes students' preconceptions to be the Aristotelian sunspot model from HOS.

> **(Simplicio)** Aristotle first laid the basis of his argument *a priori*, showing the necessity of the inalterability of heaven by means of natural, evident, and clear principles. He afterward supported *a posteriori*, by the senses and by the traditions of the ancients. (Galilei, 1967, p. 50)
>
> **(Simplicio)** … Some say, "They are stars which, like Venus and Mercury, go about the sun in their proper orbits, and in passing under it present themselves to us as dark: and because there are many of them, they frequently happen to collect together, and then again to separate." … At the same time to maintain to incorruptibility and ingenerability of the heavens. (Galilei, 1967, p. 53)

Arousing cognitive conflict by suggesting socio-cultural pressure (finding of astonishing phenomena)

Sunspots could not be explained based on previous theories (the Aristotelian sunspot model). <Socio-cultural pressure> (generation of Cognitive Conflict by anomalies) (**Students hold Aristotelian sunspot model**)

> *Teacher:* In science history, these black spots were interpreted as shadows of planets cast by light coming from stars, with the movement of shadows caused by the orbital movement of Mercury or Mars.
>
> **(Salviati)** … it may be inferred from the same changes of shape that none of these are stars or other spherical bodies, because of all shapes only the sphere is never seen foreshortened, nor can it appear to be anything but perfectly round. So if any of the individual spots were a round body, as all stars are deemed to be, it would present the same roundness in the middle of

the sun's disc as at the extreme edge, whereas they so much foreshorten and look so thin near that extremity, and are on the other hand so broad and long toward the center … (Galilei, 1967, p. 55)

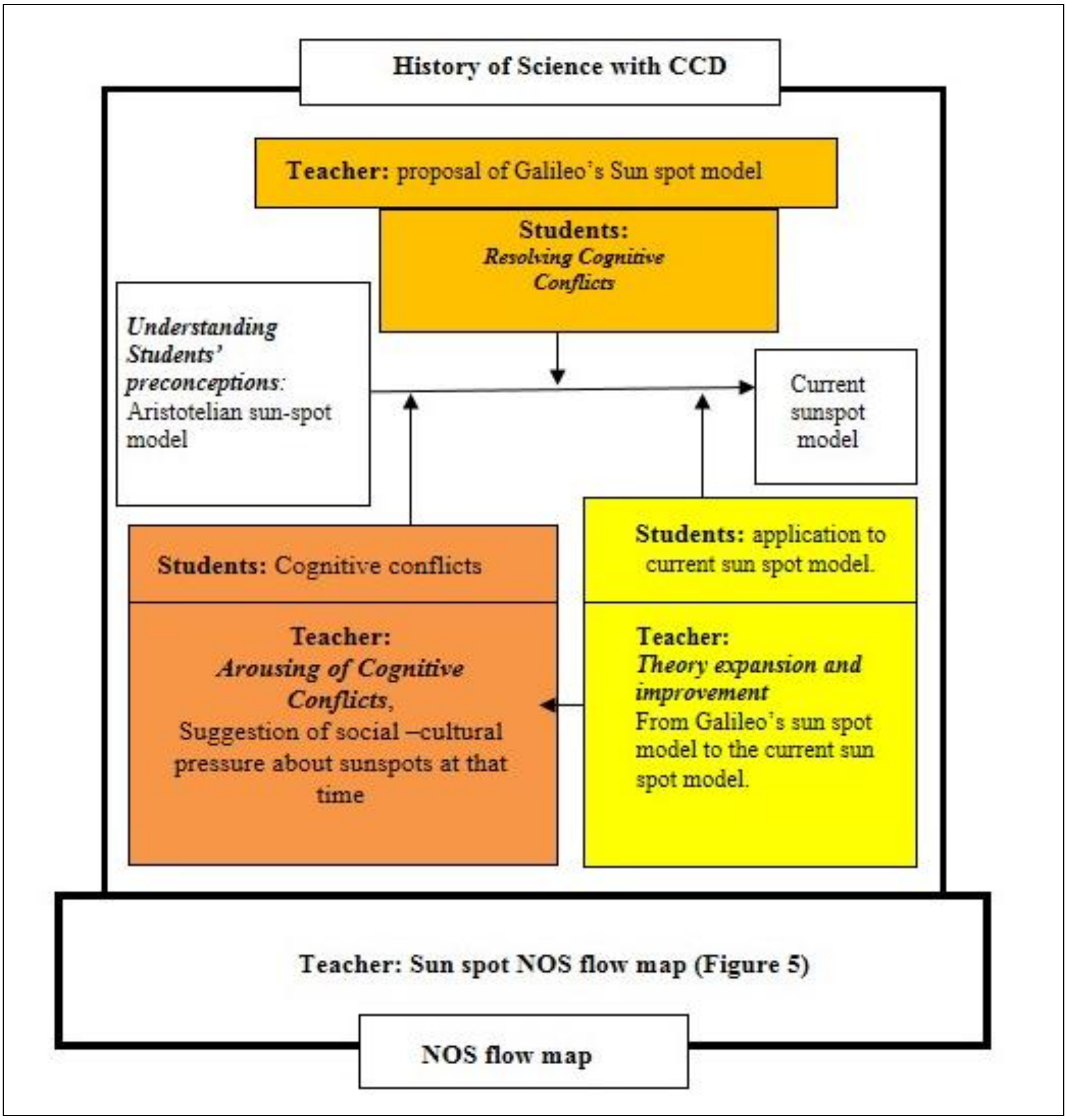

Figure 3. *Sequence of NOS instruction.*

Resolving cognitive conflict through HOS

Teacher (proposal of hypothesis): We should think that there are actual spots on the sun's surface, and their movement is caused by the rotation of the sun, as follows.

In a famous passage in *Dialogue Concerning the Two Chief World Systems*, Galileo says, through his mouthpiece Salviati:

The shapes of the spots prove the same by appearing very narrow around the sun's edge in comparison with how they look in the vicinity of the center.

> For around the center they are seen in their majesty and as they really are; but around the edge, because of the curvature of the spherical surface, they show themselves foreshortened. These diminutions of … shape, for anyone who knows how to observe them and calculate diligently, **correspond exactly to what ought to appear if the spots are contiguous to the sun**. (Galilei, 1967, p. 54)
>
> The students select an explanatory hypothesis through reject a hypothesis that can become existing alternative through the history of science.

Predicted and observed results expected by the chosen hypothesis

If the hypothesis that spots on the sun's surface move due to the sun's rotation is true, and if it is assumed that the sun has a crevice like Earth, and if the spots are observed in a location where the inner planet does not pass and their revolution periods are not consistent, then the spots will appear over a fixed period, moving in the direction of the sun's rotation.

> **(Salviati)** … which are conclusively proved to be produced and dissolved and to be situated next to the body of the sun and to revolve with it or in relation to it. (Galilei, 1967, p. 58)

Conclusion drawn by comparing predicted and observed results

Students conclude that the spots appeared over a fixed period. Therefore, the hypothesis that the spots on the sun's surface move due to the sun's rotation is supported: the sun rotates.

Theory expansion and improvement

> *Teacher:* Because the sun rotates in this way without exception, Copernicus's heliocentric hypothesis, asserting that the Earth is a planet that can move, is supported. Additionally, the theory that strong magnetic fields are the reason is improved.
>
> Given the fact that all celestial bodies share similar properties as Earth, all celestial bodies are imperfect, in contradiction to Aristotelian tenets. The Earth and the celestial bodies are comprised of the same material following the same laws of motion. Galileo's insight states that the fall of an apple toward earth's surface is related to the moon's orbit of the earth.

Final stage: reflection on explicit NOS flow map of sunspot discovery

Teacher:

A new flow map, using core elements of the NOS and the prerequisite conditions for a scientific revolution proposed by Kuhn (1996), was applied to the sunspot discovery process. The core NOS elements and Kuhn's (1996) conditions for scientific revolution are systematically related and correspond well to each other, as shown in figure 4.

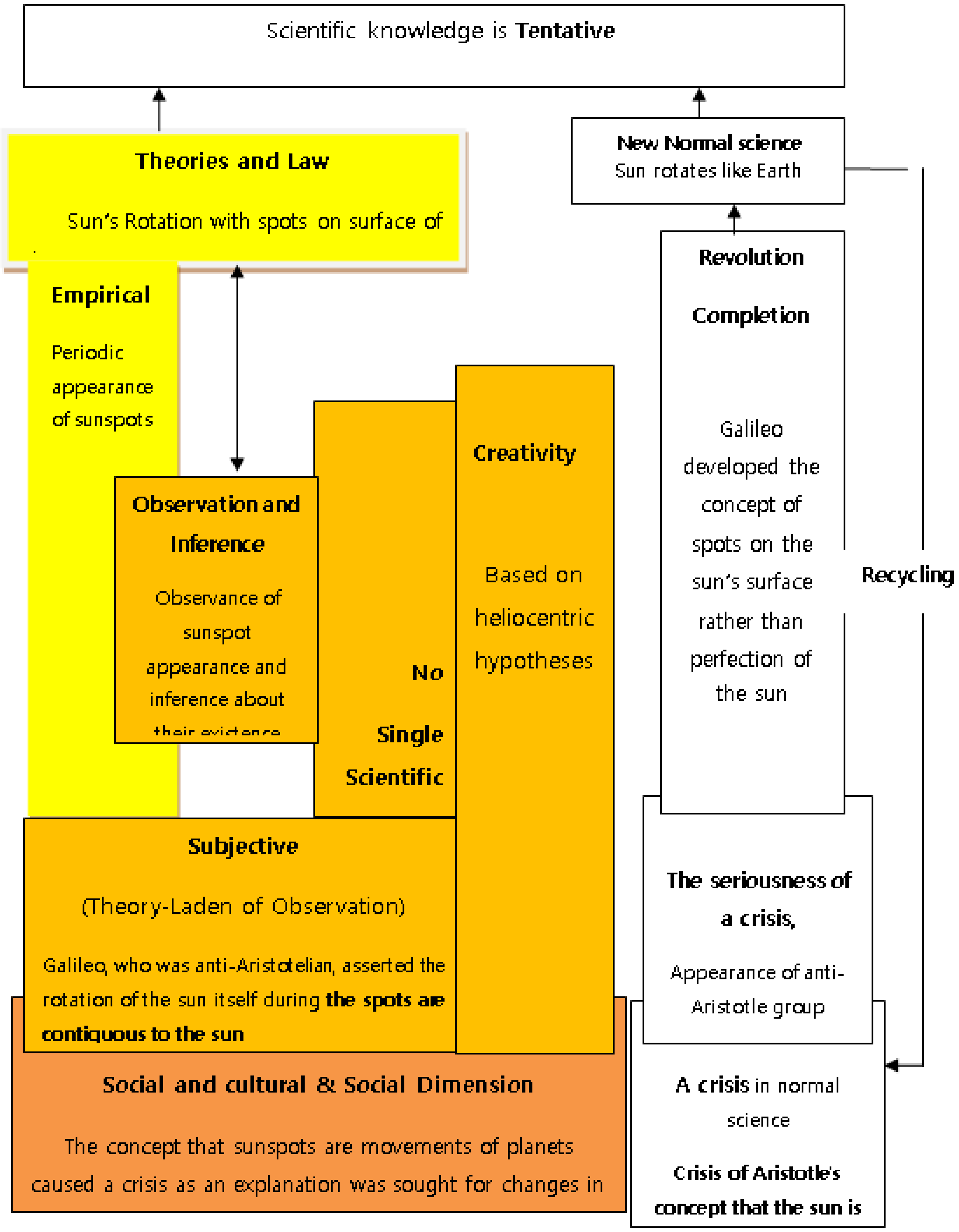

Figure 4. *NOS flow map for the sunspot discovery process.*

Test Instruments

VNOS has been repeatedly emphasized in many major science education reform efforts (Clough, 2006; McComas, 2008; McComas, Clough, & Almazroa, 1998; Deng, Chen, Tsai, & Chai, 2011), and it has been suggested as a vital component of scientific literacy (Abd-El-Khalick & Lederman, 2000a; Lederman, 2007; Millar & Osborne, 1998). Driver, Leach, Millar, and Scott (1996) delineated the importance of VNOS by explicating five potential benefits when students express sophisticated VNOS. Specifically, VNOS helps students to (1) understand the process of science, (2) make informed decisions on socio-scientific issues, (3) appreciate science as a pivotal element of contemporary culture, (4) be more aware of the norms of the scientific community, and (5) learn science content with more depth.

Lederman (2007) specifies the definition of the NOS and what key aspects it should include. He concludes that K-12 students do not possess “adequate” views of the NOS. Their misconceptions of the NOS can be attributed to the ineffectiveness of curricular or instructional approaches, teachers’ “inadequate” VNOS, and other situational variables, such as instructional behaviors, activities, and decisions implemented within the classroom context (Deng et al., 2011).

The VNOS-C probes learners’ ideas about different forms of investigation through more comprehensive questioning. This study employed a questionnaire used by Choi et al. (2009) (which included VNOS-C items 1, 2, 3, 4, 5, 8, 9, and 10 and VNOS-B item 6) to test NOS instruction using HOS. This questionnaire incorporates open-ended questions related to the definition of science, the empirical nature of scientific knowledge, the temporality of scientific knowledge, the scientific method, characteristics of scientific inference, the theory-dependence of observation, the social structure of scientific knowledge, and creative characteristics of science.

Selection of experimental group and HOS only group without CCM

Implicit NOS group using HOS only without CCM

Galileo’s process for discovery of sunspots was selected as the HOS episode for study. Scientific knowledge has a history that develops through the thought and studies of scientists over long periods of time.

Explicit NOS experimental group using HOS with CCM and NOS flow map

After having the history science group with CCM, explicitly, using the NOS flow Map including elements of nature of science, classes were carried out in order.

Data collection

After selecting the two groups in the fall semester of the 2013-2014 academic year, pre-testing (VNOS-C) on the NOS was conducted. Then, after each group’s classes were completed, the same test was conducted as a post-test.

Data analysis

The results of the test (VNOS-C) on the NOS were analyzed by dividing them into the proposed classic viewpoint (naive views) and the modern viewpoint (informed views). The elements and analysis frameworks of science are shown in Table 2. The analysis was conducted by two experts in science education, and was repeated until inter-rater reliability reached 90%. For each group, Wilcoxon verification of the pre- and post-test was conducted using SPSS 18.0™.

Table 2. *Analysis frameworks of illustrative examples for responses about the Nature of Science (VNOS –C)*

Aspect of NOS	More Naive views	More Informed views
The definition of Science	Science is absolute and **objective**.	Science depends on observations, but I don't think that science is absolute and objective by observable facts.
Empirical Nature of Science	An experiment is a sequence of steps performed to prove **only existing theories**	An experiment is a sequence of steps performed to prove proposed hypothesis and discover a new fact
The diversity Of Scientific Method	The development of scientific knowledge can **only be attained through precise experiments**	Experiments are not always crucial.. Einstein's theory of special relativity … cannot be directly tested experimentally.
Scientific knowledge as tentative	Theories in science **should be not subject to change** with interpretation of that evidence, because of disorder, and their objectivity	Everything, specially theories in science is subject to change with new evidence and interpretation of that evidence
Difference between Theory and law	Laws stated as theories and eventually became laws after repeated and proven demonstration.	A scientific law describes quantitative relationships between phenomena. Scientific theories propose new explanatory models for the world.
Difference between Knowledge and view	Scientific knowledge is **true**, Views are individual explanatory tools	Scientific knowledge are proved, but views are their opinions and thoughts
The theory-dependence of observation	Scientists reach different conclusions, because I think that **their data are not fluent and fault**, but scientists are very objective.	Both conclusions are possible because of different explanations based on their own education and background.
Social and Cultural Embeddedness	Scientific knowledge is **universal** and does not be changed by cultures and society.	All factors in society and the culture influence the acceptance of scientific ideas.
Creative and imaginative	A scientist only used imagination in collecting data … But there is **no creativity** after scientist has to be objective.	Creative and imagination are essential for entire procedure of the formulation of novel ideas … to explain why the results were observed.

Table 3. *The effectiveness about instruction of NOS about the experiment group (History of science with CCD based on NOS flow map) through VNOS-C test*

Elements of NOS	Test	The experiment group (History of science with CCD based on NOS flow map)		The History of Science group without cognitive conflicts	
		More Informed views (% Changed)	Significance probability	More Informed views (% Changed)	Significance probability
The definition of Science	*Pre*	7	*p=.000*	45 (+56)	*p*=.000
	Post	37 (+60)	*	10	*
Empirical Nature of Science	*Pre*	17	*p=.000*	25 (+30)	*p*=.000
	Post	40 (+46)	*	38	*
The diversity Of Scientific Method	*Pre*	6	*p=.000*	39 (+2)	*p=.000*
	Post	33 (+54)	*	47	*
Scientific knowledge as tentative	*Pre*	42	*p=.000*	48 (+4)	*p=.015*
	Post	50 (+16)	*	34	*
Difference between Theory and law	*Pre*	14	*p=.000*	32 (-4)	*p=.000*
	Post	48 (+68)	*	46	*
Difference between Knowledge and view	*Pre*	40	*p=.000*	49 (+2)	*p=.000*
	Post	45 (+10)	*	38	*
The theory-dependence of observation	*Pre*	44	*p=.000*	34 (-8)	*p=.000*
	Post	50 (+12)	*	7	*
Social and Cultural Embeddedness	*Pre*	8	*p=.000*	17 (+20)	*p=.000*
	Post	34 (+56)	*	8	*
Creativity	*Pre*	6	*p=.000*		
	Post	35 (+58)	*		

Table 4. *The effectiveness about instruction of NOS about the History of Science group without cognitive conflicts through VNOS-C test*

Elements of NOS	Test	More Informed views (% Changed)	Significance probability
The definition of Science	*Pre*	17	*p*=.000*
	Post	45 (+56)	
Empirical Nature of Science	*Pre*	10	*p*=.000*
	Post	25 (+30)	
The diversity Of Scientific Method	*Pre*	38	*p*=.000*
	Post	39 (+2)	
Scientific knowledge as tentative	*Pre*	47	*p=.000**
	Post	48 (+4)	
Difference between Theory and law	*Pre*	34	*p=.015**
	Post	32 (-4)	
Difference between Knowledge and view	*Pre*	46	*p=.000**
	Post	49 (+2)	
The theory- dependence of observation	*Pre*	38	*p=.000**
	Post	34 (-8)	
Social and Cultural Embeddedness	*Pre*	7	*p=.000**
	Post	17 (+20)	
Creativity	*Pre*	8	*p=.000**
	Post	8 (+0)	

RESULTS

Among the VNOS-C question categories, the experimental group scored lowest in "diversity of scientific method" in both the pre- and post-test. The HOS only group scored lowest in the "creativity" category. The "social and cultural embeddedness" category received relatively high responses. The highest scores were in "tentativeness of scientific knowledge" and "theory-dependence of observation" for both groups.

The Wilcoxon verification results of the pre- and post-test, which examine the effectiveness of NOS in both the experimental group and the HOS only group, are shown in Tables 3 and 4

The explicit NOS experimental group utilized HOS instruction with cognitive conflicts involving social and cultural pressure, based on the NOS flow map.

The five most frequent and high responses among pre-service teachers are presented below.

Students A, B, C, and F, who showed change in the "tentativeness of scientific knowledge" category, provided responses similar to the following:

> *Pre-test:* Science theories come to develop gradually along with social development. But, since science is objective, the basis is difficult to change.
>
> *Post-test:* Science starts from hypotheses. So, if society changes, the hypotheses change. Naturally, scientific theories are tentative.

Example responses of students A, B, C, and F, who also showed change in the "diversity of scientific method" category, were as follows:

Pre-test: Experiments are surely necessary. That is because science is proved by experiments different from other studies.

Post-test: Though experiments are necessary, theories can initially be like the theory of relativity in modern science. In such cases, thought experiments may be necessary rather than direct experiments. Plus, in case of paleontology, revival by experiment is impossible.

Responses of teachers A, C, and D, who showed change in the relatively high-scoring “creativity” category, were similar to the following:

Pre-test: Creativity is necessary only in the course of collecting data, because science is objective. Hence, the viewpoints of individuals should not intervene in other processes.

Post-test: Creativity is necessary in all processes, because scientific theories are tentative and the work of scientists does not go into predetermined ways.

Additionally, the responses of teachers A, B, C, D, and F, who showed change in the “social and cultural embeddedness” category, were similar to the following:

Pre-test: Science theories are universal, so if they fall under the social and cultural influences of different times and places, disturbances will be raised.

Post-test: Social and cultural values cannot help but intervene. The foundation of all science is to realize the value of influence from the societies and cultures affiliated with it.

The following results focus on student A’s responses, which were common examples.

It was confirmed that the influence and pressure of the scientists’ culture and society (+56% change) influenced subjectivity (+12%, but initial score was almost 88%), as well as observation and inference along with individual creativity (+58%), which comprise the scientists’ own scientific activity.

Due to these influences, the empirical data (+46%), or scientific products, that are obtained through observation and inference (+58%) by various scientific methods (+54%) rather than a single tool such as induction, compose and support scientific theories and rules (+68%). When socio-cultural influences change, scientists’ subjective values also change, so the theories and rules fundamentally change on the basis of empirical material attained by theory-dependent scientific activity. Therefore, scientific knowledge is tentative (+16%, but initial score was almost 84%).

“Scientism” appeared commonly in the responses of the HOS only group.

The socio-cultural influence and pressure (+20) phase of cognitive conflict—that is, the phase of dissatisfaction with the existing conception—was omitted during instruction in the NOS.

Scientific knowledge is objective, so according to scientists’ objective scientific activity (−8% change, but initial score was 76%), the empirical data (+30%), obtained using the scientific method (+2%) that is universally recognized rather than diverse, support and discover theories and rules (−4%). Because empirical data are collected objectively rather than subjectively and accumulate gradually (based on the perspective that fundamental theories and rules are elaborated on and evolve little by little, progressing rather than changing), scientific knowledge is tentative (+4%, but initial score was almost 94%).

Creative inference and observation, influence scientific activity only in collection of data, rather than affecting all scientific inquiry activity; creativity is not used in the process of searching for theories and rules (+0%).

Because there was no phase of cognitive conflict or dissatisfaction in the HOS-only group's instruction, it is confirmed that conceptual change regarding the NOS is difficult in this condition. Preservice teachers in the HOS group without cognitive conflicts did not appropriately understand "social-cultural embeddedness."

The HOS without cognitive conflicts group believed that although social and cultural value is needed initially, value should become universal in the end. However, the experimental group believed that because social and cultural value changes according to period, it is the driving force of change in scientific theories.

To explicitly make clear that creativity is used in all stages of scientific investigation, a viewpoint of modern scientific philosophy, it is necessary to show that creativity is necessary and more important than inductive reasoning in each stage.

DISCUSSION

In NOS instruction, because the elements of the NOS are linked, implicit classes using HOS only are limited. This study explicitly used HOS with CCM based on an NOS flow map we developed, targeting change in VNOS among pre-service elementary teachers. The study observed large changes when comparing questionnaires from before (pre-test) and after (post-test) NOS instruction in the experimental group, relatively different from the classes that incorporated HOS only, without cognitive conflicts involving social and cultural pressure.

In addition, the elements of the NOS are not independent but interconnected (Bartholomew & Osborne, 2004; Schwartz et al., 2012). Notably, social and cultural value is linked with the theory-dependence of observation, subjectivity, deductive characteristics, and finally tentativeness.

We emphasized that value is linked with creativity in the first stage of instruction. First, we can recognize that subjectivity and creativity, like the theory-dependence of observation, are influenced most by social-cultural embeddedness. Unlike the HOS-only group, which demonstrated low effects, the instruction was very effective in the experimental group. Second, the general perception of the HOS-only group was that most scientists use creative imagination only in data collection or establishment of hypotheses. On the other hand, the experimental group perceived that scientists use creativity in all stages of scientific inquiry. Third, subjectivity is connected with the theory-dependence of observation through deductive characteristics, and ultimately with tentativeness. In the case of the HOS-only group that were not introduced to cognitive conflicts involving social and cultural pressure, little change was seen in perspective on the NOS element of tentativeness of scientific knowledge.

CONCLUSION

It is valuable to introduce students at the elementary level to some ideas developed by Kuhn (Eflin et al., 1999; Rea-Ramirez et al., 2008). Thus, we developed a flow map for key aspects of the NOS based on Kuhn's concept of constructivism, which was applied well to Galileo's discovery of sunspots, a main events in the history of astronomical science, as a historical case study.

First, many of the ideas embedded in any understanding of the NOS are difficult to present as clearly teachable propositions. In particular, it should be known that subjectivity and creativity are most influenced by the theory-dependence of observation and social and cultural embeddedness. Hence, explicit educational strategies are necessary that present the elements of the NOS as connected in a holistic manner rather as separate entities, because responses are analyzed holistically, seeking connections and consistencies (Lederman et al., 2002; Schwartz et al., 2012, p. 689).

Second, we suggest the use of an explicit NOS flow map to teach the key aspects of the NOS as a historical case study, with a good case being the Copernican Revolution, one of the main events in the history of astronomical science.

Third, our explicit NOS flow maps incorporate the instructional sequences of the NOS, HOS, SCK, and POS with the CCM. However, initially, we present a strategy that begins with the most important core aspects of the NOS, then introduces supportive SCK and HOS to explain these aspects through cognitive learning strategies (CCM). The concepts are presented explicitly and reflectively, providing a means for teachers to help students reconstruct their initial views of the NOS toward the target views.

A comparison of responses to reviews of NOS pre-test studies using the explicit NOS flow map containing general terms showed high levels of agreement about the tentativeness, subjectivity, and creativity of scientific knowledge using concrete examples from "Galileo's explanations of sunspots." These findings indicate that students showed change in their understanding of NOS approaching more modern views. For the NOS flow maps including HOS, SCK, and POS, the recommended instructional sequence begins with social and cultural pressure (cognitive conflicts) and progresses to revolution (resolution of cognitive conflicts).

Pre-service elementary teachers' understanding of the NOS was explored through an explicit NOS flow map developed as an NOS instructional tool. The instructions involved a combination of cognitive conflict strategies in HOS episodes (Galileo's discovery of sunspots) with accompanying responses consisting of illustrations and questions. The activity was designed to spend 50 minutes on HOS including conflict strategy, and 30 minutes on the explicit NOS flow map including all elements of the NOS.

Findings indicated that students showed change toward more modern views of the NOS. They demonstrated understanding of the tentativeness of scientific knowledge based on supporting empirical data gathered through observed and imagined scientific activities with creativity and the effect of social and cultural pressure.

HOS knowledge should be taught in our science teacher programs. Some knowledge of HOS for the NOS can be as useful to students as to working scientists. Although this study did not demonstrate that HOS played a dual role in significantly increasing student scores for both the NOS and SCK, it is clear that HOS provides instructional resources for science teaching if it is explicitly contextualized into domain-specific content. A science teacher of science must also bring to the classroom the attitude and worldview of a scientist, because experiencing the processes of science alone is not sufficient. To achieve this, a basic understanding of Kuhn's philosophy of science is necessary. Therefore, an explicit NOS flow map incorporating cognitive conflict strategies could be a promising NOS method and an explicit and reflective tool to enhance science teaching and learning.

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