



Suggesting a NOS Map for Nature of Science for Science Education Instruction

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ABSTRACT

The aims of this research are 1) to explore the inter-relationships within the individual elements or tenets of Nature of Science (NOS), based on the dimensions of scientific knowledge in science learning, and 2) to consider Kuhn's concept of how scientific revolution takes place. This study suggests that instruction according to our NOS Flowchart should include the tenets of NOS. The aspects of NOS that have been emphasized in recent science education reform documents disagree with the received views of common science. Attitudes about science can have a significant effect on scientific literacy. In education theory, the understanding of content lies in the cognitive domain, whereas attitudes lie in the affective domain. There are three major dimensions of learning in science: knowledge, skills, and attitudes. Additionally, it is valuable to introduce students at the primary level to some of the ideas developed by Kuhn. Key aspects of NOS are, in fact, good applications to the history of science through Kuhn's philosophy. Therefore, an NOS Flow Map could be a promising means of understanding the NOS tenets and an explicit and reflective tool for science teachers to enhance scientific teaching and learning.

Keywords: nature of science, NOS flow map, Attitudes, skills, knowledge, scientific literacy, Kuhn's philosophy

INTRODUCTION

According to the United States National Center for Education Statistics, scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity (NRC, 1996, 2012). Project 2061 is a long-term, three-phase undertaking of the American Association for the Advancement of Science (AAAS) that is meant to contribute to the reform of education in science, mathematics, and technology in the United States with respect to improving scientific literacy. A research project under the auspices of Project 2061, Science for all Americans (1989, 2011), has claimed that in order to obtain scientific literacy, scientific knowledge, skills, and attitudes must be acquired in school. These claims have led the United States to reform science education, requiring both individual achievements related to science and adherence to national standards through Benchmarks for Science Literacy and National Science Education Standards.

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State of the literature

- Nature of Science for science Education can occur in inter-relationship. Integrated NOS education must include tenets of NOS design as a basic for creating connections to concepts and practices from science.
- However, many research on NOS design in Science Education focused on separated tenets of NOS.
- Thus, there is the need for integrated inter-relationship activities that uses NOS framework to improve students learning especially interest towards NOS.

Contribution of this paper to the literature

- The outcomes of this study provide inter-relationship NOS Flow Map that exposing NOS Instruction design process in integrated scientific literacy education.

In the past few years, the role of Nature of Science (NOS) in supporting scientific literacy has become widely institutionalized in curriculum standards internationally (Allchin, 2014). Understanding NOS is a central component of scientific literacy (AAAS, 1990; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) and a central tenet in science education reform (e.g., NRC, 1996). Because scientific literacy involves an understanding of NOS, it is assumed that one will achieve scientific literacy if one obtains a fuller understanding of NOS (Meichtry, 1992; NRC, 1996). Rather than being memorized, however, NOS is experienced; and when we experience NOS, we achieve enhanced scientific literacy. Thus, the scientific enterprise is composed of at least two parts—processes and products—which involve attitudes as well as facts, theories, laws, and applications as a result of doing science (Martin, 2012, p. 40). NOS requires assumptions involving knowledge products (McComas et al., 1998, p. 4); thus, NOS involves understanding the limits of the scientific method, the nature of scientific knowledge, and the historical situations of their developments (Lederman, 1992, 1999).

Despite continuing disagreements about a specific definition for NOS, at a certain level of generality and within a certain period of time (Allchin, 2011; 2012), those aspects of NOS that are of interest for this study are generally agreed on (Martin, 2012; Akerson et al., 2010; Akerson et al., 2007; Lederman, 2006; Lederman et al., 2002, among others). As summarized by Lederman and his colleagues, these aspects are as follows:

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); necessarily 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. (Lederman et al., 2002, p. 499).

This research aims to explore the inter-relationship among the individual elements or tenets of the NOS in the context of the dimensions of scientific knowledge in science learning and the procedure scientific revolution as defined by Kuhn in observing Copernicus's revolution, in order to explore the development of scientific knowledge in the history of science. Abd-El-Khalick et al. (2008) subdivided NOS into 10 different features, in which social dimensions are separated from social and cultural embeddedness. Within this framework, social dimensions and cultural embeddedness are combined into one feature for this research. Practically, we constructed an NOS Flow Map and applied it to the evolution of the structure of the atom. Because we limited our discussion to Kuhn, we look at what cognitive science has to say about how individuals learn science (Carey, 2009; Clement, 2008; Nersessian, 2008) and show the parallels in how novel scientific knowledge develops, especially demonstrating how individuals (novices and experts alike) succumb to the same pressures. We offer examples from science history that provide explicit ways to reflect about this connection. This approach may help students be more aware of their own learning and empower them to take some ownership in it.

Abd-El-Khalick, Waters, and Le (2008) listed aspects of NOS that have emerged from science education reform documents: science is empirical, inferential, creative, theory-driven, tentative, includes social dimensions, is socially and culturally embedded, and adherent to no single scientific method, as well as to definitions of theories and laws that are specific and nonhierarchical. The authors caution, “[i]t cannot be overemphasized, however, that these aspects are intricately interrelated” (p. 837). It is the interrelationship that is our focus, particularly as it relates to the inseparability of the rational from the social aspects of science (Fuselier et al., 2015).

THE DIMENSIONS OF LEARNING IN SCIENCE: KNOWLEDGE, SKILLS, AND ATTITUDES

Zeitler and Baruffaldi (1988) encourage educators to use the experience of scientific enquiries, scientific attitude, and basic scientific knowledge in teaching, which are all integrated as scientific literacy. Therefore, in this study it is necessary to present NOS as a combination of these three elements 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.

The **knowledge dimension** of learning in science includes understanding of NOS and technology, science content, and unifying themes or concepts. Through skill activities, students can learn about NOS and technology as parallel human endeavors to create explanations for natural phenomena (science) and solve problems of human adaptation to the environment (technology) (Bybee, 1989).

The **skills dimension** of learning includes bodily kinesthetic skills (gross, fine motor, and eye-hand coordination) as well as training of the senses. Students can also learn skills in science processes such as inference, data analysis, and hypothesizing (AAAS, 1967) and general organizing skills such as information gathering, problem-solving, and decision making (Bybee, 1989). Cooperative group arrangements and the need to interact with a variety of new materials provide opportunities for students to develop social (interpersonal) skills as well as intrapersonal and meta-cognitive awareness skills.

In the science education community, the rational or epistemological characteristics of science are typically tied to empiricism, the process of inquiry, differences between inference and observation, and the tentative nature of scientific conclusions (Abd-El-Khalick, 2012; Irzik & Nola, 2014; Lederman et al., 2002).

The **attitudes dimension** of learning includes attitudes of science. Attitudes of science are those habits of mind cultivated by scientific investigators for maintaining the integrity of the inquiry and the validity of the information. These include attitudes such as being skeptical, relying on data, and accepting ambiguity (Bybee, 1989).

As well as exploration of effects of SSI interventions on students' interest and motivation, some researchers have focused on the effects of Science-Technology-Society (STS) issues on students' attitudes towards science (Sadler, 2009). Yager et al. (2006) used an STS issue for one class and compared this class with a class following the standard middle school science curriculum. The attitude of students in the intervention class was found to be higher than in the comparison class. Lee and Erdogan (2007) conducted another STS intervention study for middle and high school students and found similar results with Yager et al.'s (2006) findings that students developed positive attitudes towards science. However, SSI are different from the science issues in that they do not only focus on science content but also on social dimensions of this science content. An SSI approach is characterised by a reconceptualisation of the STS approach, and it focuses on not only social dimensions of science and technology but also on students.

A "consensus view" (Erduran & Dagher, 2014, p. 5) of NOS emerged recently in science education research that describes social dimensions as including the theory-laden nature of scientific knowledge, creativity, and social and cultural embeddedness (Abd-El-Khalick, 2012; Lederman et al., 2002). Within this framework, social dimensions and cultural embeddedness are collapsed into one feature and separated from other attributes.

In this research, theory-laden nature of scientific knowledge is included in skilled detention and attitude detention interchange. But creativity is involved in skill detention rather than altitude dimension, we describe that the two "constantly interact with each other"

Martin (2012, p. 40) defined science as a process by which knowledge is produced. Thus, the scientific enterprise comprises at least two factors – processes and products. The products

of science include the facts, concepts, theories, laws, and applications and attitudes that occur as a result of doing science.

Zeitler and Barufaldi (1988, p.10) defined scientific literacy as the melding of scientific investigative experience, attitudes, and basic knowledge. Therefore, acquiring scientific literacy should be well coordinated between a basic knowledge of science and experiential exploration and attitudes toward science.

One development in this regard is the establishment of Project 2061, a publication consisting of a set of recommendations “spelling out the knowledge, skills, and attitudes all students should acquire as a consequence of their total science experience” (AAAS, 1989, p. 3) in order to be regarded as scientifically literate (Laugksch, 2000).

Martin (2012, p.27) has described 'attitudes' as another scientific product, different from facts, concepts, generalization, theories, and laws, etc. These attitudes are formed by individual experiences and explorations; in turn, they affect our learning with explorations, which are once again affected by these attitudes.

The recommendations contained in SFAA (Science for All Americans, AAAS, 1989) reflect a comprehensive definition of scientific literacy, and the values, attitudes, and skills that scientifically literate individuals should possess and exhibit (Laugksch, 2000).

These “habits of mind” are clearly spelled out and include values “inherent in science, mathematics, and technology; the social value of science and technology; the reinforcement of general social values; and people's attitudes toward their own ability to understand science and mathematics” (p. 133), as well as particular skills (computational skills, manipulative and observation skills, communication skills, and critical-response skills; AAAS, 1989).

In this research, the following terms are used for the processes of science learning that consist of attitude, skill, and knowledge: **Scientific attitudes** refer to the social dimension, social and cultural changes, and subjectivity (theory-ladenness). **Scientific skills** do not refer to specific scientific methods but rather to imagination and creativity, observation and inference, and subjectivity (hypothesizing). **Scientific knowledge** refers to law and theories, and the elements of nature of science the NOS necessary to achieve wider scientific literacy (see [Figure 1](#)). In particular, subjectivity consists of hypothesizing (Skills, AAAS, 1989), and theory-ladenness (Attitudes, Martin, 2012).

In this study, the dimensions of science learning in science should be understood as supporting the tenet that scientific knowledge is tentative and revisionary.

A “consensus view” (Erduran & Dagher, 2014, p. 5) of NOS has emerged recently in science education research that describes the social dimension as including the theory-laden nature of scientific knowledge, creativity, and social and cultural embeddedness (Abd-El-Khalick, 2012; Lederman et al., 2002). Within this framework, social dimensions and cultural embeddedness are collapsed into one feature and separated from other attributes in this

research, whereas the schema used by Abd-El-Khalick et al. (2008) subdivides NOS into 10 different features, in which social dimensions are separated from social and cultural embeddedness. Longino (1990) described social dimensions as including “constitutive values associated with established venues for communication and criticism within the scientific enterprise which serve to enhance the objectivity of collectively scrutinized scientific knowledge” (Abd-El-Khalick et al., 2008, p. 838), within intrinsic effects. The social and cultural aspects of NoS are described as processes by which scientific knowledge claims are “affected by their social and historical milieu” (Niaz & Maza, 2011) or “embedded and practiced in the context of a larger cultural milieu” (Abd-El-Khalick et al., 2008, p. 839), within extrinsic effects.

One important aspect of science is the **observation** of events. However, observation requires **imagination and creativity**, for scientists can never include everything in a description of what they observe. Hence, scientists must make judgments about what is relevant in their observations. Empirical theory would argue that there is no imagination and creativity in observation because it happens automatically, though it is filtered by the senses and brain. It is the *interpretation* of those records in our brain, the empiricist would say, that relies on creativity and imagination. Hanson (1958, p. 31), however, claims that interpretation happens simultaneously with visual experiences, rather than interpretation occurring strictly after observation.

The role of **creativity and imagination** in the development of scientific knowledge also has implications for the supposed objectivity of science; even so-called “objective facts” in science are not really free from **subjectivity**. Scientists’ backgrounds, theoretical and disciplinary commitments, and expectations all strongly influence their work. These factors produce a mindset that affects what scientists investigate, how they conduct their investigations, and how they interpret their observations. That is, the observations themselves are typically motivated by, guided by, and acquire meaning in the context of specific theoretical frameworks (Hanson, 1958; Kuhn, 1996).

As two prominent examples, Aristotle (384-322 B.C.) and Galileo (1564-1642) both interpreted motion along a horizontal surface. Aristotle noted that objects, after an initial push, always slow down and stop. Consequently, he believed that the natural state of an object is to be at rest, supporting the geocentric hypothesis that, in his social and cultural context, distinguished between the celestial world and the terrestrial world.

Galileo imagined that if friction could be eliminated, an object given an initial push along a horizontal surface would continue to move indefinitely without stopping. He concluded it was just as natural for an object to be in motion as to be at rest. He did so with a leap of the imagination. Galileo made this leap conceptually without actually eliminating friction, supporting the heliocentric hypothesis that unified the celestial and terrestrial worlds’ laws, based on the simplicity of Neo-Platonism.

These two examples demonstrate the **distinction between observations and inference**, which is significant in science because these two types of scientific knowledge give rise to different kinds of scientific claims. The **laws** express a relationship that can describe what happens under specific conditions, but **scientific theories** offer explanations for why something happens. Additionally, because both laws and theories are based on tentative knowledge (observation and inferences), neither is absolute.

When considering its empirical nature, it is important to remember that scientific knowledge is a product of **both observation and inference**. Observations constitute the empirical basis of scientific knowledge: they are descriptions of natural phenomena that may be directly perceived by the senses (or instrumental extensions of the senses). Inferences are conjectures beyond observable data. The distinction between observations and inferences in science is significant because these two types of scientific knowledge give rise to different kinds of scientific claims. Science involves more than the accumulation of countless observations—rather, it is derived from a combination of observation and explanations derived from observations, and it often involves entities that are not directly observable.

Recent research on both the history and philosophy of science has furthered our understanding of the social aspects of science, which has been understudied so far, and has emphasized the need to consider scientists, the socio-cultural environment, and attitudes together when we investigate NOS. That is, in addition to the systematic collecting of information about nature and the scientific knowledge obtained through that process, we need to include scientists' socio-cultural backgrounds as a prominent influence in their selection of special processes for acquiring scientific knowledge, values, and attitudes (Abruscato, 1982; Trowbridge & Bybee, 1986).

Bauer (1994) said that scientific knowledge is composed of the following: fundamental concepts in science, the nature of scientific activities, and the role of science in society-culture. One who achieves these three types of knowledge is a person well-equipped with scientific literacy. In light of these elements, scientific literacy is actually a part of historical and cultural literacy. Anyone who understands that scientific progress is limited through a filter of scientific agreement can develop their science literacy, even if he or she does not know the content of science very well. Accordingly, our research ranks these scientists, socio-cultural contexts, and attitudes as foundational in terms of affecting the development of scientific knowledge (see [Figure 1](#)).

In the next section, we will investigate how Kuhn's philosophy and history of science are connected with NOS. Here, we must look at Kuhn's emphasis on scientific work as essentially communal and social because natural science also has a social character: namely, the scientific community. In a "classical" analysis of the emergence of creative products in a phase model, Wallas (1926) distinguished four phases or stages: information, incubation, illumination, and verification. A discussion of the role of society in creativity—as in Csikszentmihalyi's (1966) emphasis on the importance of socio-cultural validation—indicates

Table 1. The views about the elements of NOS

The elements of NOS			
Cognition (Irzik & Nolar, 2014)	Cognitive-Epistemic System	Social-Instructional System	Productions
Epistemology (Irzik & Nolar, 2014)	Rational aspects	Social aspects	
Scientific Literacy (Zeitler & Barufaldi, 1988)	Skill	Attitude	Knowledge
	Process of inquiry	Social dimension	Productions
Inter-relationship NOS	No scientific methods, observation & inference (theory – dependence, creativity)	Social dimension & Social and Cultural effects, (theory –dependence, creativity)	Scientific knowledge, Empirical

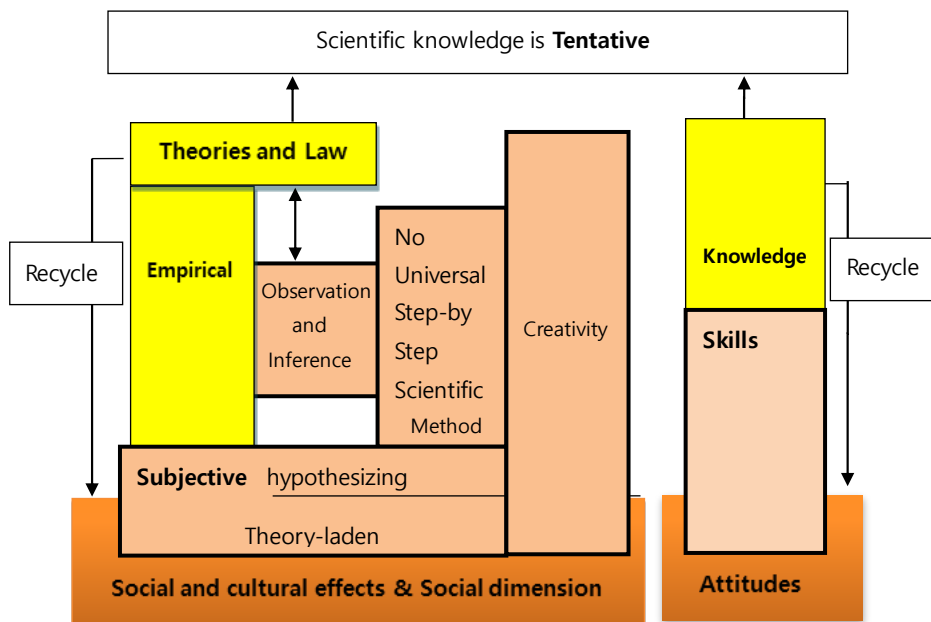


Figure 1. The tenets of NOS and the dimensions of learning in science

the need to account for both the communication of novelty to other people and their assessment of its effectiveness. Thus, Wallas's four stages need to be extended by adding two further stages at the end: communication and validation.

According to Cropley (2008, p. 72), the necessity for the creativity of a human agent who is acting with intention suggests that an initial stage of preparation should be taken into account. The solution may emerge into one’s consciousness all at once, thus seeming to have appeared from nowhere and creating a subjective feeling of creativity without perspiration. This would explain why some creative people overlook the phase of information and incubation in describing their own creativity. Therefore, creativity involved in both process and social dimension, in this research. The thesis of theory-ladenness of observations, roughly, is the idea that observations are affected by theoretical presuppositions (Chalmers, 1999;

Hanson, 1958; Gillies, 1993), accepted it as nature of observations (Brown, 1977). While empiricism does not deny imagination or creativity in observation.

Science is about the study of the natural world, and about understanding and representing its phenomena. Science is about making inferences and observations through creativity and subjectivity based on social dimension and social and cultural effects, drawing conclusions and developing theories, models and explanations based on empirical data through these scientific enquiries. However scientific investigations are not the only investigations that are based on empirical data—just think of the work of the fictional detective. Scientific investigation and these discipline's investigations share some features, but of course differ in others (e.g., the object of study though obstinate peer reviews).

THE HISTORY AND PHILOSOPHY OF SCIENCE IN THE DEVELOPMENT OF SCIENTIFIC KNOWLEDGE

We have seen that scientific literacy encompasses an understanding of both science content knowledge and NOS. School science, however, tends to focus only on teaching content, often ignoring NOS (Clough, 2006). Therefore, scientific literacy needs to be considered in a more expansive way by considering its technical, social, and cultural elements, and emphasizing, explicitly and reflectively, that scientific literacy involves not only content knowledge but also the key aspects of NOS. Science teaching should not only reveal the complex interactions of science, technology, in society but also encourage students to participate as citizens in the decision making of the relevant issues. A better understanding of the nature of science (NOS) and the ability to make informed decisions on science-related issues are both recognized as the two important components of scientific literacy (Liu, et al., 2011). It is further argued that knowledge of NOS is a prerequisite for one to make up his/her opinion about a science-related issue (Kolstø, 2001). Cobern (1996) stated that although science educators more often speak of scientific literacy as the primary goal for science education rather than a worldview, the concept of literacy advocated entails the concept of worldview.

Anomalies are regarded as serious if they are important with respect to some pressing social need. An individual scientist's decision will depend on the priority he or she gives to the various factors, such as simplicity, a connection to some pressing social need, and the ability to solve some specified kind of problem (Chalmers, 1999, pp. 114-115). Therefore, selecting a paradigm is a continuous effort by the disciplinary successors that continue work on solving it. For example, Galileo and Kepler's study, which prioritized an aesthetic sense of Copernicus's system, proposed a new paradigm that solved Copernicus's earlier problems, thus performing their roles as disciplinary successors (see Figure 2). There was one major and important similarity between Kepler and Galileo. They were very much alike in their desire to bring mathematics and natural philosophy together (Henry, 2012, p.109) based on aesthetic features of Copernicus heliocentric system.

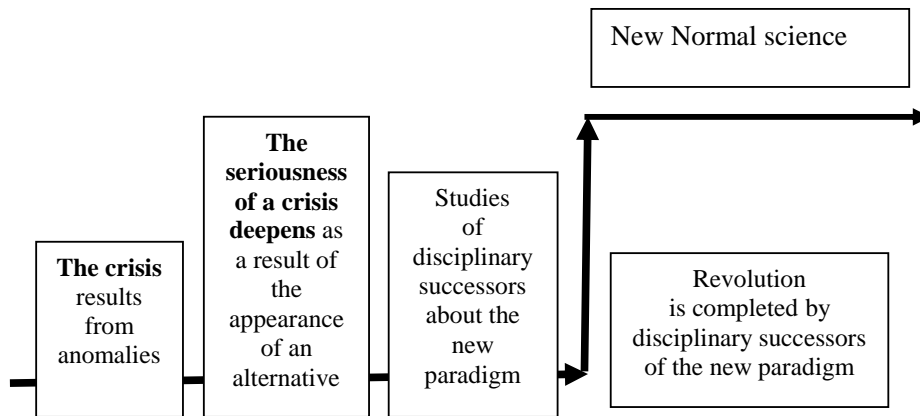


Figure 2. The conditions and procedures of Kuhn’s scientific revolution

Accordingly, our study arrives at an NOS Flowchart setting forth key aspects of NOS, which we explore from an important case in astronomy history – namely, Copernicus’s scientific revolution – by focusing on Kuhn’s theory of scientific revolution (Oh, 2014).

Kuhn’s scientific revolution and the tenets of NOS

Longino’s (2002) work builds upon her earlier examination of social influences in science and both of these treatments are embedded in a larger examination of science as simultaneously social and rational (Harding, 1991) that can be traced back to Kuhn (Allchin, 2014), based on social process in the science community. Thus, this idea of a flow map, is a tool of simplification, also it would be some restricting, because a Kuhnian revolution may be one way to consider the process of science.

This section explains the social and cultural embeddedness and social dimension of scientific knowledge and the crisis of normal science as Kuhn explained it. Using a flowchart, which is a tool for simplification, also has some restrictions in that a Kuhnian revolution may be only one way to consider the process of science. However, as Eflin, Glennan, and Reisch (1999) observe,

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).

Thus, even if one is unwilling to accept Kuhn’s incommensurability thesis, we can recognize that learners should make a genuine effort and extended commitment toward achieving the kind of conceptual shift necessary to make the historical approach useful for

learning about science (Abd-El-Khalick & Lederman, 2000). A middle-of-the-road approach seems to be suggested by some of the NOS tenets given in the American Association for the Advancement of Science reports.

We turn now to examining the steps or stages in Kuhn's concept of a scientific revolution. **A crisis in normal science** occurs as a result of a number of serious anomalies. In the case of Copernicus, scientists have formulated several elaborate and differing story lines about the heliocentric hypothesis at the time of Copernicus. The dominant problems centered on "calendar reform" and "complexity" in explaining the heavens (Charmers, 1999, p.113). Kuhn described episodes of theory change as tumultuous periods during which scientists with established venues for communication and criticism judged competing theories using a variety of criteria, including social influences (Sadler, 2004).

While STS education typically stresses the impact of decisions in science and technology on society, it does not mandate explicit attention to the ethical issues contained within choices about means and ends, nor does it consider the moral or character development of students. As Zeidler et al. (2002) point out, "Socioscientific issues then, is a broader term that subsumes all that STS has to offer, while also considering the ethical dimensions of science, the moral reasoning of the child, and the emotional development of the student" (p. 344). (Zeidler, Sadler, Simmons, & Howes, 2005). Danielson (2001) points out that, before Copernicus the earth was thought to be at the lowest, basest, grossest position in the universe and furthest from the pure realm of God's abode. It was the pits—the bottom of the universe rather than the most important place. Galileo described the change introduced by Copernicus in the following words which he placed in the mouth of Salviati: "As for the earth, we seek ... to ennoble and perfect it when we strive to make it like the celestial bodies, and, as it were place it in heaven, from whence your philosophers have banished it" (Danielson 2001). This scientific revolution of Copernicus can be seen that even at that time was under the influence of religious and ethical values as well as socio-cultural values, and harmony rather than conflicts between science and religion in resolving the risk owing to selection for uncertainty

The seriousness of the crisis in normal science then deepens as a result of the appearance of an alternative. **Subjectivity** enters at this stage, for although the crisis in the paradigm is recognized in terms of a socio-cultural need and the problem is partially solved by the submission of new alternatives, new problems are posed with the new paradigm. However, for the disciplinary successors of the new paradigm, new alternatives emerge as the severity of the crisis intensifies for the paradigm. In other words, study is begun to solve the new problems. The subjective and theory-dependent empirical data indicate the study direction of the new paradigm.

One of Kuhn's ideas about the nature of science is the **theory-ladenness of observations**. In ancient Greece, Aristarchus suggested that the earth may rotate on its axis and revolve in an orbit around the sun. Almost 2000 years later, Copernicus also came to a conclusion about the system of the universe based on the combination of the earth's two motions about the Sun.

In particular, he could explain the retrograde motions of planets without the complex epicycles suggested by Ptolemy (Cohen, 1985, p.45).

The Copernican system has more problems in the observational sense than the Ptolemaic system, because Aristotle's idea of the celestial bodies accepted the notion of the uniform circular motion in what is called a natural motion. However, it strongly attracted such disciplinary successors as Galileo, Kepler, and Newton because of its beauty. In other words, Neo-Platonism, which was popular at that time, emphasized simplicity and beauty (qualitatively simple and harmonious), whereas the Ptolemaic system tried to explain in a more and more complicated way. Theory-ladenness relates to social and cultural changes, as well as subjectivity. In terms of accuracy, Ptolemy's model is better than Copernicus's model. As well, Neo-Platonism is based on a certain degree of comprehension, not just simplicity. "Putting the Earth in motion around the Sun was that it immediately suggested that Copernicus had not just a workable astronomy but a seemingly coherent cosmology" (Henry, 2012, p.71).

A scientific revolution is then completed by disciplinary successors who follow a new paradigm. Science's necessary reliance on empirical evidence is what distinguishes it from other disciplines (e.g., religion, philosophy). Although this evidence may be explained by the new theory, new evidence will still be predicted and estimated. For example, as Galileo continued his studies, he was able to use a mathematical abstraction to solve the tower argument that had been used as a counterevidence of the earth rotation. He argued, as well, that the parallax of stars was difficult to investigate because many cannot be seen by the eye and are visible only through a telescope and that observation of stars is different from that of planets owing to the very distant locations of the former. Galileo also provided data to support the heliocentric theory through the phase changes of Venus. "The phases of Venus offered positive support for the heliocentric system. In the geocentric system, Venus is always more or less between the Sun and the Earth and must always appear as a crescent. In the heliocentric system, Venus travels behind the Sun and can appear nearly full – which the telescope reveals" (Westfall, 1971, p. 13).

Empirical Evidence supporting Copernicus's heliocentric hypothesis **<Observations and Inferences>**

Given the empirical evidence for Copernicus's heliocentric theory, mathematical abstraction and idealization in thought experiences became very important in Galileo's research, especially in the study of dynamics. Galileo demonstrated that **inference** is very important, beyond accurate observation on natural phenomena.

Empirical data that have a favorable influence upon Newton's theory **<Observations and Inferences>**

Based on the observations of Tycho Brahe, Kepler was able to discard the annoying epicycles with a planet's elliptical orbit rather than a circular orbit. Kepler's inference is more

significant than Brahe's because he could not estimate an elliptical orbit directly from Tycho Brahe's data. Rather, he explained Brahe's observations because he thought of an elliptical orbit through an intermediate form from an initial circular orbit.

An accurate elliptical orbit is difficult to derive from observation because an accurate elliptical orbit revolves only when there is only one planet with a sun of infinite mass. Thus, the abstraction work of inference is required. Therefore, rather than estimating scientific empirical data from simple observations, inference is absolutely necessary, and this requires a scientist's creativity. Moreover, not only is inference required to interpret observation data but also it becomes the foundation of predicting further observation data.

Law and theory are both in the so-called "hierarchy of credibility," found in most science textbooks, which presents categories of scientific knowledge/ideas (i.e., observations, hypotheses, theories, laws/principles) in an ascending list of credibility or certainty. Individuals often hold the common sense, hierarchical view of the relationship between theories and laws presented in such lists. In this view, theories become laws as they accumulate supporting evidence over numerous years. It follows from this notion that scientific laws have a higher status than scientific theories.

The common notions relating to theories and laws are inappropriate because, among other things, theories and laws are different kinds of knowledge and the one cannot develop or be transformed into the other. Laws are *statements or descriptions of the relationships* among observable phenomena. Theories, by contrast, *are inferred explanations* for observable phenomena.

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 that relate to changes in the physical states of matter, others that relate to the rates of chemical reactions, and still others that relate to heat and its transfer, to mention just a few.

Newton, in order to explain Galileo's law of falling, which was the rule on natural phenomena and Kepler's empirical law of an elliptical orbit, constructed gravity based on the idea that a planet's revolution was a causal mechanism rather than a teleological cause, as in Aristotle's thought. However, Newton first constructed the law of gravity and then used Kepler's law to justify his gravitational hypothesis. This example demonstrates that law and theory are mutually dynamic and that they have different roots rather than being connected in a hierarchical order.

<No Universal Step by Step Scientific Method>, <Individual Creativity> The development of scientific knowledge is based partly on human **imagination and creativity**. Scientific knowledge is not simply the product of logic and rationality. Scientists follow many

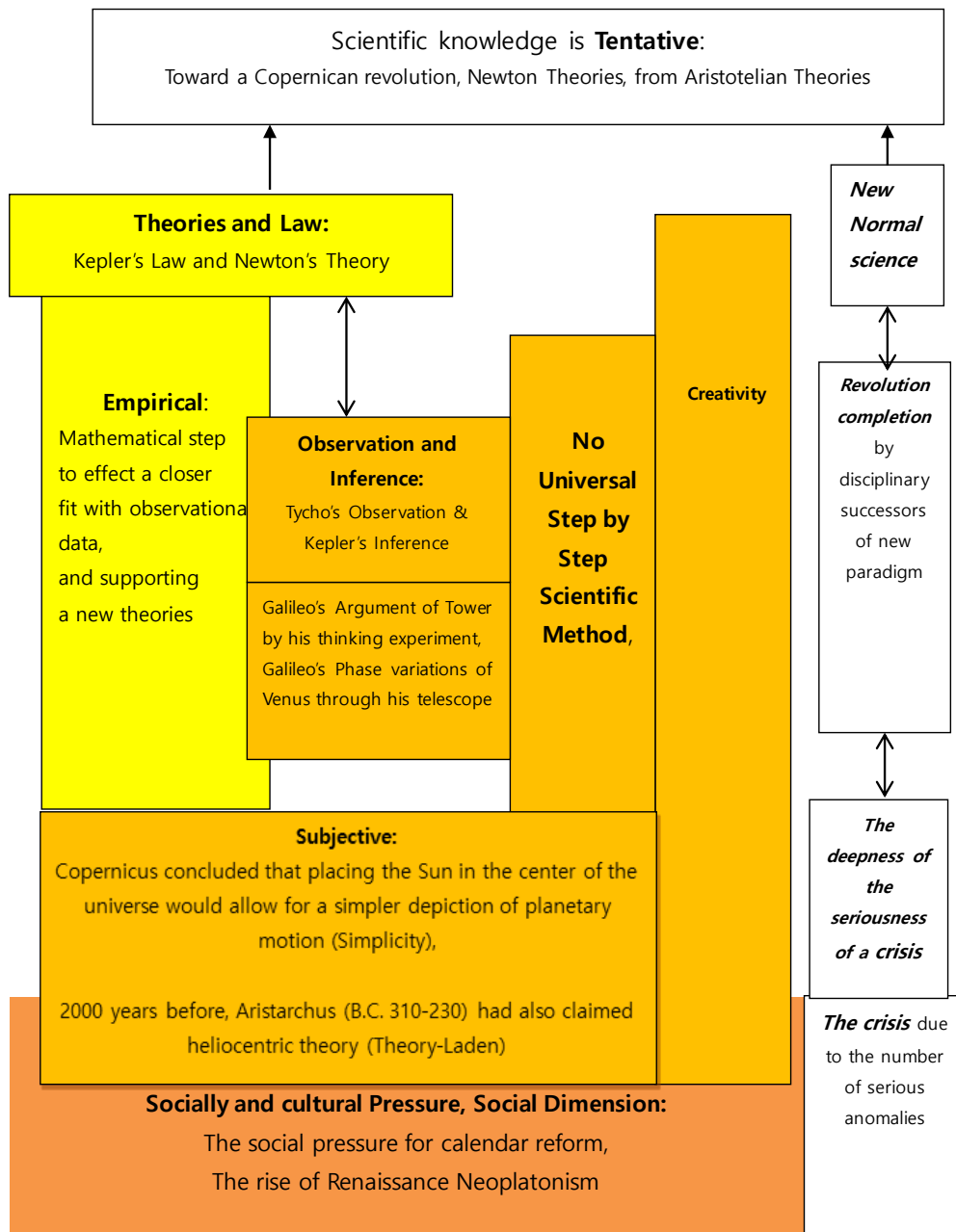


Figure 3. The Copernican Revolution: The Flow Map of the Nature of Science (NOS)

and various methods in order to produce scientific knowledge (AAAS, 1993; NRC, 1996; Shapin, 1996). Throughout scientific history, diverse disciplinary successors have not constructed certain laws or theories by a simple collection of data and logical induction; rather, their work has been pursued creatively through insight to solve the problems inherent in a new paradigm.

<Law and Theory> Galileo's and Kepler's theories both played a role in enhancing Copernicus's theory. Nonetheless, Copernicus's theory for comprehensive physics was required as foundational for further developments. Newton then replaced Galileo's law of circular inertia with the law of linear inertia. Of course, Newton's most significant contribution was the law of the universal gravitation, and by this theory, Newton could explain Kepler's law of planetary motion and Galileo's law of falling.

The stage of the new Normal Science and its Recycling (Expansion)

<Tentative Character of Scientific Theory> In Newton's theory system, the celestial and terrestrial worlds are unified as one, and each object moves with the force of Newton's law of motion. Newton's integrated thinking allowed the proposal of a law of physics which could explain observed phenomena, be used to make predictions, and satisfactorily account for phenomena both on the earth and in the universe (AAAS, 1993). As soon as Newton's physics was constructed, it was applied in detail to astronomy. For example, it could be used to explore the phenomenon in which Kepler's law, owing to the limited mass of the Sun and the force between planets, could not be accurately applied to the planets (Chalmers, 1982, p. 74). However, the discrepancy of Newton's mechanics with electromagnetism and the explanation of Mercury's perihelion shifting provided an opportunity for Einstein to construct his new theory of relativity.

In sum, scientific knowledge is a product of recycling the revolution process toward discovery of a new philosophy and theory system as well as an accumulation procedure through revision and development. Therefore, conflicting ideas may arise from various interpretations of the same data based on individual theory.

THE HISTORY OF SCIENCE (HOS) AND THE TENETS OF NOS BASED ON THE HISTORY OF SCIENCE OF KUHN AND COGNITIVE CONFLICT STRATEGIES: INSTRUCTION IN THE NATURE OF SCIENCE (NOS)

Allchin (1999) promoted the concept of "cognitive resources" (Giere, 1988; Harding, 1991) in producing more objective scientific knowledge through the functions of scientists in a community. The idea is that each individual brings to the table his or her own unique cognitive resources as shaped by life experience and enculturation. A scientific community comprises a diversity of cognitive resources, thus offering a better system of checks and balances that is more likely to reveal or avoid bias. It is the inseparability of the cognitive and the social that strengthens scientific understanding. Allchin (1999) connected this view of science with science pedagogy by proposing a framework constructed by historians, philosophers of science, and science studies scholars (e.g., Giere, 1988; Gould, 1981; Longino, 1990; Merton, 1973). This framework encourages teaching the positive and negative influences of values on science as well as the impact of science's values on society.

In the history of science, not every science process-skills instructional sequence or scientific inquiry activity is either an implicit or explicit attempt to enhance learners'

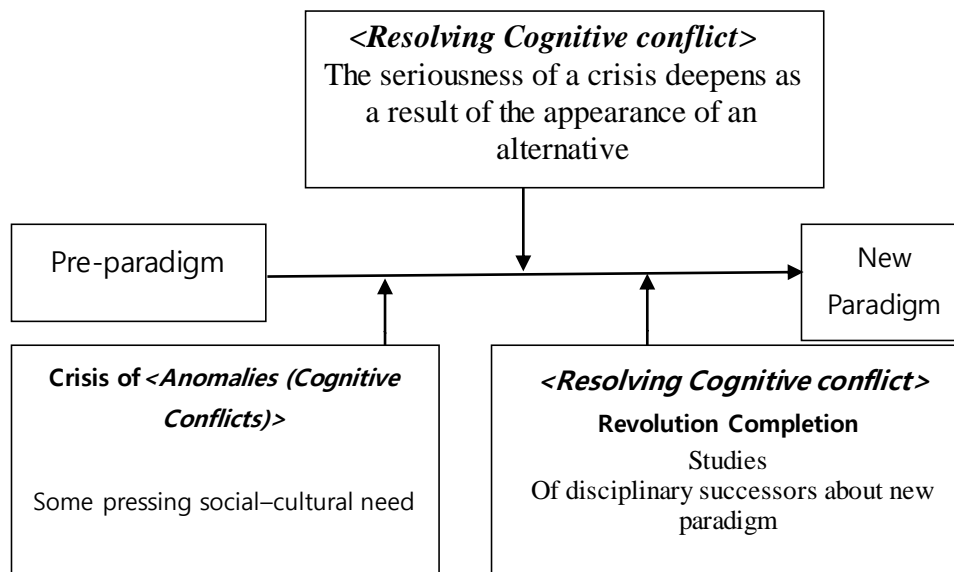


Figure 4. The History of Science and Cognitive Strategies

conceptions of NOS. The basic difference between implicit and explicit approaches lies in the extent to which learners are helped to come to grips with the conceptual tools, in this case specific aspects of NOS, which would enable them to think about and reflect on the activities in which they are engaged (Abd-El-Khalick, & Lederman, 2000).

Thus, history of science teaching is focused on an implicit NOS instructional approach using cognitive conflicts only with reference to the history of science rather than suggesting the elements of NOS. However, we have developed here, and suggest as an instructional tool, a NoS flowchart that details an explicit NOS approach to instruction in terms of the dynamic changes found in the history of science.

The lessons combine cognitive conflict strategies (see Oh, 2011) in an episode from the history of science (specifically, the evolution of atomic structure), with accompanying responses consisting of illustrations and questions (Figure 4).

The Evolution of Atomic Structure

Lights coming from celestial bodies are classified in the continuous spectrum, the emission line spectrum, and the absorption line spectrum. We can reveal all the components of a celestial body by analyzing the observed spectral lines, strictly analyzing the atomic spectrum (continuous spectrum, absorption line spectrum and atomic spectrum. The atomic spectrum is the light spectrum emitted or absorbed by atoms, which are theoretically in free states. The absorbed lights are closely related to the energy levels of electrons in an atom, because the light is emitted or absorbed when an electron's energy level changes.

In this way, we can understand the features of an atom and its model through understanding the spectrums. However, this fact has not been known or recognized from the beginning of science. As hundreds of years passed, many scientists proposed several theories and hypotheses, and we have finally come to understand atomic structure and features.

First of all, we need to understand that the prerequisite conditions of a scientific revolution as proposed by Kuhn are related to the core elements of NOS in order to understand the history of atomic structure for each star's spectral type.

The Crisis in normal science owing to a number of serious anomalies

<Socio-cultural pressure, communication, and criticism within the scientific enterprise >

Physicists who were contemporaneous with Rutherford's experiments tried to discover the order in the complex line spectrums of light. In 1884, Balmer discovered a simple rule for calculating the line spectrum wave of light as emitted from a hydrogen atom, but he could not explain why the rule was right.

Anomalies are regarded as serious if they are important with respect to some pressing social need. When anomalies come to be regarded as posing serious problems for a paradigm, a period of pronounced professional insecurity sets in. Attempts to solve the problem become more and more radical as the rules set by the paradigm for the solution of problems become progressively loosened.

<Resolving Cognitive conflict >

<Subjective><Creative> due to the theory-ladenness of observations

"The seriousness of a crisis deepens when a rival paradigm makes its appearance" (Chalmers, 1999, p. 114). An individual scientist's decision will depend on the priority he or she gives to the various factors, such as simplicity, the connection with some pressing social need, the ability to solve some specified kind of problem, and so on. In 1913, Bohr created a familiar planetary model by applying Plank and Einstein's quantum theory to Rutherford's atomic model. Above all, Bohr could prove that his equation was well matched to Balmer's equation. Nonetheless, most scientists were uncomfortable at that time because Bohr introduced the quantum, a hitherto unknown concept.

Revolution Completion by disciplinary successors of a new paradigm

<Empirical data>

Balmer's data about the line spectrum of light was the starting point for Bohr's model. In addition, Frank-Hertz's experiment provided support for the existence of atomic energy levels.

<Inference and observation><Creative>

The concepts of the particle properties of light and the wave properties of all moving matter, both experimentally hypothesized, were proven as facts.

<Theories and Law>

Although Bohr's equation is a kind of empirical law, Schrödinger's equation is an explanatory theory based on the fact that all things have their own wave properties.

<Creative>

De Broglie's matter wave theory became the basis of Bohr's model and Schrödinger's equation.

<Conflict Map: conflict 2 resolution by critical events>

<Various methods rather than universal step-by-step research methods>

The reason that these equations were created is not caused by the existence of clear scientific law.

New Normal science stage and its new cycle: the Expansion of Normal Science

<Tentative Scientific knowledge>

Atomic model structure has reached the current electron cloud model, having passed through Rutherford's planetary model and then Bohr's model over several scientific revolutions. These various models have demonstrated the history of atomic model development history through an application of Kuhn's observations on the history of science.

CONCLUSION

In this research, the process of science learning is held to consist of attitudes, skills, and knowledge: **scientific attitudes** include social and cultural changes, and subjectivity (theory-ladenness; Martin, 2012), **scientific skills**, while involving no single scientific method, include imagination and creativity, observation and inference, and subjectivity (hypothesizing; AAAS, 1967); and **scientific knowledge** includes laws, theories, and empirical evidence. The elements or tenets of NOS necessary to achieve scientific literacy are connected with scientific content.

We insist that none of these aspects should be considered apart from the others. Thus, the key aspects of NOS should be viewed in this study as interdependent, dynamic, explicit, and reflective. Empiricists argue that our perception gives us objective facts about the world, configuring the foundations of science, and that general laws and theories are inductively produced, based on those facts. However, we maintain that judgments and inferences on observable facts in a specific situation will change depending on the person, the culture, and the theoretical school.

That is, under the themes of **social and cultural background**, including communication and criticism (**Social dimension**) within the scientific enterprise, perception is formed and developed in a decisive manner by the **subjectivity of observers**, which involves their cultural and theoretical background, expectations, and perspectives. Such considerations are handled under the heading of **the theory-ladenness of observation** in the philosophy of science. Additionally, **law**, which shows regularity, and **theory**, which requires our creativity, should be separated. We insist that **law** (regularity) and **theory** (creativity) should be considered as a dynamic combination rather than separated because of the theory-ladenness of observation. Likewise, most modern philosophers of science have questioned the hierarchical/dichotomous relationship between laws and theories (Giere, 1999; Nias & Maza, 2011, p. 5).

The development of scientific knowledge involves making observations about nature. That is, observations do not equate to **scientific methods**, which are represented as universal step-by-step processes. This additional aspect is what we have alluded to as “no single scientific method” but rather a host of methodologies to produce scientific knowledge (Lederman et al., 2002; Bell, 2006). Finally, because objective law or theory is not produced from objective facts, a scientific theory is, indeed, tentative.

This research has proposed a new flow map, using core elements of NOS and the prerequisite conditions of a scientific revolution proposed by Kuhn (1996), to apply to the atomic understanding process. The core elements of the NOS and Kuhn’s (1996) prerequisite conditions for a scientific revolution are systematically related and shown to correspond well to each other.

However, our explicit NOS approach instructions include the history and philosophy of science in a dynamic exchange with the history of science as focused on implicit NOS approach instruction. In this way, we can use historical case studies and encourage students to analyze for the multi-faceted effects of the direction of scientific knowledge creation (see Allchin, 2013, 2012, 2011; Irzik & Nola, 2011; Osborne et al., 2003).

The main limitation of the present investigation is that the learning and teaching outcomes described here and teaching according to the NOS Flowchart have not been presented to pre-service teachers and students. A formal assessment of the effects of the NOS Flowchart on learning outcomes will be needed in future research.

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