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ABSTRACT

This study aimed to help the teachers clarify and understand the nature of science (NOS), as well as classroom practice through the implementation of the constructivist teaching model. Ten elementary science teachers were involved in a year-long in-service program that included a series of intervention courses. Following the intervention courses, participants were asked to visit classroom demonstrations and attend the debriefing meetings. Meanwhile, the teachers were asked to implement the constructivist teaching model in their science classroom practices. Prior to and following the program, participants responded to an open-ended questionnaire designed to assess their understanding of the NOS. Throughout their teaching, participants' lesson plans and classroom videotapes were collected for explicit reference to the NOS. After the intervention program, the participants were interviewed to validate their responses to the open-ended questionnaire. The results indicated that the teachers were found to possess proper understandings of several important aspects of the NOS before the intervention, but could not describe how to teach science in terms of the NOS. After the intervention, some teachers could delineate how they taught several aspects of the NOS through the constructivist teaching model. In addition to the view of inductivism, some teachers' classroom practices inclined to constructivism and revealed the creative and social aspects of the NOS. However, the teachers did not place teaching the NOS as important as other aspects, and they claimed that they had not taught NOS explicitly due to some constraints. The implications of the findings are discussed. (Contains 72 references.) (Author)

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Abstract

This study aimed to help the teachers clarify and understand the nature of science (NOS), as well as classroom practice through the implementation of the constructivist teaching model. Ten elementary science teachers were involved in a year-long in-service program that included a series of intervention courses. Following the intervention courses, participants were asked to visit classroom demonstrations and attend the debriefing meetings. Meanwhile, the teachers were asked to implement the constructivist teaching model in their science classroom practices. Prior to and following the program, participants responded to an open-ended questionnaire designed to assess their understanding of the NOS. Throughout their teaching, participants' lesson plans and classroom videotapes were collected for explicit reference to the NOS. After the intervention program, the participants were interviewed to validate their responses to the open-ended questionnaire. The results indicated that the teachers were found to possess proper understandings of several important aspects of the NOS before the intervention, but could not describe how to teach science in terms of the NOS. After the intervention, some teachers could delineate how they taught several aspects of the NOS through the constructivist teaching model. In addition to the view of inductivism, some teachers' classroom practices inclined to constructivism and revealed the creative and social aspects of the NOS. However, the teachers did not place teaching the NOS as important as other aspects, and they claimed that they had not taught NOS explicitly due to some constraints. The implications of the findings were discussed.

Keywords：the nature of science, science teaching, teacher development.

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Purpose

The purposes of this study were to implement the in-service program designed to help the elementary science teachers clarify their understanding of the NOS, and translate the NOS, as well as their beliefs about teaching science.

Introduction

Scientifically literate individuals should have an acceptable understanding of the nature of science (AAAS, 1989). Although there appears to be a perennial concern about students' conceptions of the NOS, little progress has been made toward the achievement of this instructional goal. Indeed, there is presently much dissatisfaction with the levels of both teachers' and students' understandings of the NOS (Duschl, 1990; Lederman, 1992).

Many curricula have been designed with the aim of improving learners' conceptions of the NOS. Research evaluating these curricula and strategies has demonstrated that the successful ones are those that introduce the nature of science through examples from the history of science, or that address the nature of science directly (Lederman, 1992). Based on the conclusions from research, two activities of demonstration and one activity of reading the history of science were used in this program to show several aspects of the NOS.

Literature Review

The study of teacher learning to teach the NOS is an interwoven research because it is situated at the intersection of several fields of research and practice: research and theory on teacher professional development, on teaching practice, on learning, on relationship between education and society, and on the nature of science. The theoretical framework for this study is derived from the analysis of literature on the NOS and knowledge base for teaching the NOS.

The Nature of Science

One of the most often cited goals of science education in the past four decades has been to improve the scientific public (e.g., American Association for the Advancement of Science [AAAS], 1990,1993; National Research Council [NRC], 1996; Department of Elementary and Junior High School Education [DEJHSE], 2000). An "adequate" conception of the nature of science is considered to be an important attribute of the scientifically literate individual (Collectte & Chiappetta, 1994). Unfortunately, research studies have found that students do not possess adequate conceptions of the nature of science. For example, Aikenhead and Ryan (1991), Ryan and Aikenhead (1992) used the Views on Science-Technology- Society (VOSTS) instrument to assess high school students' viewpoints on the epistemology of science. They found that the majority of the students' hold naïve views contrary to the contemporary epistemology of science: Using the "Test on Understanding Science" (TOUS). Mackay (1971) concluded that secondary students lacked sufficient knowledge of the relationship between experiments, hypotheses, models, and theories: With a Likert-scale instrument "Nature of Scientific Knowledge Scale" (NSKS). Although the above studies used different assessment instruments, they revealed that there is a consistent finding that students do not possess adequate conceptions of the nature of science.

In addition to the assessment of students' understanding about the nature of science, several researchers turned their attention to teachers. After conducting a questionnaire to 1000 science teachers. Behnke (1961) found that over 50% of the science teachers felt that scientific findings were not tentative. By comparing the TOUS scores between 51 biology teachers and 87 high ability high school students, Miller (1963) showed that 68% of the high ability students scored higher than 25% of the teachers. Using the Wisconsin Inventory of Science Process (WISP). Carey and Stauss concluded that not only prospective science teachers (1968) but also experienced science teachers (1970) in their studies did not possess adequate conceptions of the nature of science.

The evidence showing the inadequate views of students and teachers with regard to the nature of science has caught attention from science educators, especially the research findings on teachers. Continuing efforts have been taken to study the relationship between teachers' beliefs about the nature of science and their teaching practices (Brickhouse, 1990; Gallagher, 1991; Lederman & Zeidler, 1987). Significant relationships have been found by Brickhouse and Gallagher, Meanwhile, efforts have also been taken to identify the factors which may affect teachers' understanding of the nature of science. It was found that academic variables (e.g., college grade point average, college science course, or science grade point average) could not be used to improve science teachers' conception of science (Carey & Stauss, 1970). In addition, teaching experience does not contribute to a teacher's understanding of the nature of science (Billeh & Hasan, 1975; Carey & Stauss, 1970).

The perspective of the NOS is derived from historians, philosophers, and sociologists of science and education who argue that knowledge about the scientific enterprise is potentially more important than knowledge content (Duschl, 1990). However, the characterizations of the NOS remain fairly general, and there are some changes in defining the NOS through years.

In the early 1900s the NOS objective was expressed in terms of increased emphasis on the scientific method "so as to better train students' mental faculties" (Hurd, 1960); in the 1960s the objective was linked to the advocated emphasis on scientific process and inquiry (Welch, 1979); and most recently it has been included as a critical component of scientific literacy (American Association for the Advancement of Science, 1989; National Science Teachers Association, 1982; Rutherford & Ahlgren, 1990).

More recently, the NOS was defined as an individual's beliefs, values and assumptions inherent to the development of scientific knowledge (Hammrich,1997; Lederman, 1992; Lederman & Zeidler, 1987). Using concept map strategy, Nussbaum (1989) classified the philosophies of scientific knowledge into three schools: empiricism and positivism, rationalism and constructivism.

Empiricism and Rationalism were both schools held that once knowledge is acquired, it can be described in absolutist terms, such as "true", "proven", "confirmed", "right", and "correct". During the 17th through the 19th Centuries, the Empiricist view seemed to overpower that of the Rationalists.

In the beginning of the twentieth century, Philosophical, psychological and logical arguments have accumulated against the possibility of ever *proving* or *confirming* knowledge (Popper, 1959). This led to the proposal that "knowledge" is not discovered, but that it is a human construction (and is always subjective). Thus, Constructivism replaced the "absolutism" of the Empiricist and Rationalist traditions. Constructivism presupposes that theory precedes observations, and that observations can be selected and conducted only through theoretical expectations.

While all constructivists hold that theories are bold speculations proposed *creative* minds, they differ in the manner in which their supposedly better theory be selected. Some argue that the selection should and does occur only on the basis of *inner* disciplinary criteria (e.g. rational-logical, empirical). In the most extreme form of this approach, proposed first in 1934 by Popper (1959). Others argue that the selection occurs under the influence of *outer* disciplinary factors (e.g., the personality of the scientist, socio-psychological processes in the scientific community, prevailing societal conceptions, institutional conditions, and political pressures) as well as *inner* disciplinary factors. According to this view there are no normative criteria for selecting theories. Kuhn (1970) represents the extreme form of this latter approach. Lakatos' (1970) and Toulmin's (1972) views represent an intermediate perspective.

Science educators (Abd-El-Khalick, Bell & Lederman, 1998; Smith & Scharmann, 1999; Eflin, Glennan, Reisch,1999) recognized that most disagreements about the definition of such a highly prized educational outcome are irrelevant to K-12 instruction. That is, K-12 students will never be, nor should they be, miniature philosophers or historians of science. The disagreements that continue to exist among philosophers, historians, and science educators are far too abstract for K-12 students to understand and far too esoteric to be of immediate consequence to their daily lives.

Smith and Scharman (1999) acknowledge that there should be an agreement on what level of understanding of the NOS students should experience so that they can become both intelligent consumers of scientific information and effective local and global citizens. Under this notice, they justified that the important learning outcome should be to get students to understand the characteristics that make something more or less scientific and to be able to judge any claim by those criteria. Besides that, the level of treatment of the NOS matching the level of students' knowledge, abilities, and intellectual development should be considered. Subsequently, they proposed two sets of descriptors to judge the relative merits of knowledge claims. One set of characteristics is about the objects and process of study.

(a) Science is empirical.
(b) Scientific claims are testable/falsifiable.
(c) Scientific tests or observations are repeatable.
(d) Science is tentative/fallible.
(e) Science is self-correcting.

The other set of descriptors is about the values of science. These descriptors give clues about the judgment of a particular scientific theory.

(a) Science places a high value on theories that have the largest explanatory power.
(b) Science values predictive power.
(c) Science values fecundity.
(d) Science values open-mindedness.
(e) Science values parsimony.
(f) Scientists demand logical coherence in their explanations.
(g) Scientists value skepticism.

In addition, Smith and Scharman (1999) suggested that students should be able to distinguish between observation and inference, hypothesis and theory, etc. Students must also understand the nature of valid scientific investigation (including understanding of variables, controls, etc.) so as to be able to evaluate the validity of scientific propositions.

Another approach to nature of science perspectives is provided by Toulmin (1972) and Kuhn (1970) who argue that sociological roles significantly affect what eventually comes down as a scientific decision. According to this view, values, human interests, and political aspects influence interpretations of what counts as science; personal and societal factors, social negotiation, and communications among communities of scientists affect scientific decision-making (Cunningham, 1995).

In terms of research on translating the knowledge the NOS into classroom practices also reveal the different perspectives in defining the field. The foci of studies have been multifaceted, including what Meichtry (1993) describes as either knowledge studies or scientific enterprise and nature of scientist studies. For example, Duschl (1990) argues that an analysis of the role of theory development in the acquisition of scientific knowledge can guide what is taught in the classroom and, ultimately, what conceptions about the nature of science are transmitted to students. Lederman (1995) also investigates the nature of scientific knowledge, but from the standpoint of its tentativeness and how this is translated into classroom learning. Shamos (1995) likewise addresses science's tentative character and argues that "how much of the ultimate truth we actually know depends upon how well we phrase our questions of nature, that is, how carefully we design our experiments (p.51).

Abd-El-Khalick, Bell & Lederman (1998) chose some general aspects of the NOS as criteria for the development of an open-ended questionnaire that included seven open-ended items. The aspects of the NOS assessed were the tentative, empirical, creative, and subjective nature of science; the role of social and cultural contexts in science; observation versus inference; and the functions and relationships of theories and laws. Apparently in addition to the process characteristics and inner disciplinary criteria for judging the validity of science, social and cultural factors were also considered as part of the characters of the NOS.

Knowledge Base for Teaching the NOS

The fundamental thought of teacher professional development, derived from different paradigms, has evolved from competence base (Rosner, 1977) to knowledge base Shulman (1987), and then reflective teaching model (Elliott, 1992). Although the views of teacher learning have changed, knowledge base for teaching still plays an important role in education reform. For example, effective reflection teaching requires adequate content knowledge and content-specific analytical knowledge; without knowing what to teach, there is no teaching competence. The implication is clear that knowledge base plays an fundamental role for teaching. Shulman (1987) acknowledged that the professional knowledge base is crucial for good teaching, and listed several dimensions of this knowledge base. Among these dimensions are content knowledge and pedagogical knowledge (PCK).

Content knowledge is composed of knowledge of the substantive and syntactic structures of a discipline (Grossman et al., 1989). Substantive knowledge refers to knowledge of the global structures or principles of conceptual organization of a discipline. It includes knowledge of facts, concepts, and principles within a content area and knowledge of the relationships between these. Syntactic knowledge includes knowledge of the "historical and philosophical scholarship on the nature of knowledge" in a discipline (Shulman, 1987, p.9). It refers to knowledge of the principles of inquiry and values inherent to the field, and of the methods with which new ideas are added and deficient ones are replaced by those who produce knowledge in that field. Applied to the sciences, syntactic knowledge corresponds to an understanding of the nature of science.

In order to help teachers transform their knowledge into forms attainable by their students, Anderson (1987) provided a conceptual framework of the nature of scientific knowledge. He characterized this disciplinary scientific knowledge as having three major components: structure, function, and development. The structure refers to the relationships among scientific facts, concepts, and procedures. It stands for the organizing principles about which facts and principles are interwoven in a dynamic fashion. This knowledge may serve as a precursor to understanding the empirical and holistic nature of science. The function relates to the social and personal activities. It is with such knowledge that the teacher can relate science to the everyday life activities and experiences of students, this knowledge relates to the public nature of science. The development of knowledge can be understood as the historical process through which knowledge assumed its current dynamic form. The teacher can present the concept at a level that matches the developmental level of the student. Knowledge of the development of science seems to be most intimately linked to the tentative, probabilistic, replicable, humanistic, and historic nature of science. It follows that inherent to the knowledge of the structure, function, and development of science as formulated by Anderson (1987) is an understanding of the nature of scientific knowledge.

Based on the above analysis of the literature, it appears that teachers should have three kinds of knowledge regarding to teach the NOS. First, they should understand the structure、function and development of the intended scientific concept. Second, they should know the nature of learning and finally, they should have ability to use proper pedagogical knowledge to transform the NOS with the above knowledge into classroom practice, help students construct their understanding of the NOS.

Constructivist Pedagogy and Teacher Professional Development

Many science educators recommend the application of constructivism to teaching (e.g., Cheung & Taylor, 1991; Cleminson, 1990; Roth, 1990; Vosniadou, 1991). Constructivist theory maintains that learners bring to classrooms ideas that affect new information received. What a student learns, therefore, results from the interaction between what is brought to the learning situation and what is experienced while in it. Some constructivist science educators have advocated the use of conceptual change approaches in science education (e.g., Gunstone & Northfield, 1992; Hewson & Hewson, 1988; Neale & Smith, 1989; Roth & Rosaen, 1991; Stofflett, 1991). Conceptual change pedagogy is grounded in constructivist learning theory, recognizing that powerful theories are brought to the classroom and affect the learning of new material. This instructional theory holds that learners must become dissatisfied with their existing conceptions, as well as find new concepts intelligible, plausible, and fruitful, before conceptual restructuring will occur (Posner, Strike, Hewson, & Gertzog, 1982).

The lack of efficient way to teach the NOS may be attributable in part to how student processed information in teacher education. After years of learning content in didactic classrooms, teachers commonly view science as a body of absolute facts that are proven or verified by scientists (Aguirre, Haggerty, & Linder, 1990), and they teach science as such. Therefore, if content and pedagogical knowledge are reciprocal, it follows that teachers should experience the learning of content in conceptually based classrooms so that they can better teach for conceptual understanding and facilitate the growth of accurate views of the nature of science, (Hewson et al., 1992; Stofflett & Stoddart, 1994).

Teacher education typically uses a presentation and modeling approach (Ball & Feiman-Nemser, 1998; Floden, McDiarmid, & Weimers, 1989); however, simply telling and showing teacher the NOS will not be sufficient to accommodate their traditional preconceptions (Stofflett, 1991). The NOS like scientific knowledge, will not occur through replication but rather through reconstruction. If teachers are to change their views of science teaching, they must undergo a process of conceptual change themselves. Unfortunately, teacher education courses are not typically designed to facilitate the development of the conception of the NOS. I will argue in this article that teachers construct knowledge of the NOS and NOS pedagogy in an interrelated manner, and that conceptual change teacher education can facilitate the development of conceptually based understandings of both.

Social constructivism and metacognition are two important views for teacher development. Teacher development can be thought of as human development, a major aspect of which is the development of self-identity and emotion. Bell and Gilbert (1996) proposed the social constructivist view of learning in teacher development which recognized the following components:

- Knowledge is constructed by people.
- The construction and reconstruction of knowledge is both personal and social.
- Personal construction of knowledge is socially mediated. Social construction of knowledge is personally mediated.
- Socially constructed knowledge is both the context for and the outcome of human social interaction. The social context is an integral part of the learning activity.
- Social interaction with others is a part of personal and social construction and reconstruction of knowledge.

The term metacognition can be used to refer to learner's awareness of their thoughts, beliefs and ways of coming to know about the processes of learning and teaching. Reflecting on one's beliefs about teaching and learning activities (for adults and school students), the status of knowledge, and learning styles can be seen as an aspect of metacognition that is important to the teacher development process.

The notion of the teacher as a critical inquirer is best approached through a consideration of the "reflective practitioner", which is a concept that has received considerable attention over the last decade or so, in teacher education and elsewhere, as a result of the writing of Donald Schön (Schön, 1983, 1987, 1991). It has gained prominence at the expense of the then-established approach, which required a novice professional to learn sequentially theoretical knowledge, then applied knowledge, and then how to use that applied knowledge in practice. Schön advocated a very different approach, based on the premise that, when actually practicing a profession, an individual displays: knowledge-in-action; reflection-in-action; and reflection-on-action.

Taken together, many reflection-on-action sessions make use of written materials, in the from of diaries, journals, or case study accounts, which Grimmett (1988) has suggested may be used in one of three ways. First, written materials could be copied as accounts of model or ideal practice, which in practice in so far as it can be done, might elicit reflection. Secondly, a series of accounts of case studies might be used to stimulate an appreciation of the importance of specific contextual issues during their comparative evaluation. Thirdly, written materials could serve as a source of insight for the direct appreciation of personal practice. A teacher is being invited to view the materials as a metaphor for their own practice. The materials may be used to inspire questions about personal practice, or may cause the restructuring of some personal experience, or a re-examination of some taken-for-granted belief. Another approach to sharing the experiences of one teacher with a group, is through the use of narratives (Bell, 1994).

Reflection is a skill that is inherently part of constructivism, particularly personal constructivism. A social constructivist view of learning and knowledge is related to the notion of critical inquiry and social reconstructivism. Professional development as a part of teacher development involves not only the use of different teaching activities but also the development of the beliefs and conceptions of teaching, learning, science and science education, underlying the activities. It may also involve learning about science.

Methods

Multiple methods were used in this research including questionnaire, non-participate observation, and interviews. An open-ended NOS questionnaire was use to evaluate the teachers' understanding of the NOS. In terms of non-participate observation, the videotaped science lessons and teaching plans were watched and analyzed to assess the teachers' teaching practices. Finally, the transcripts of stimulate interviews was used to validate the participants' responses to the NOS questionnaire, and elucidate the factors that impacted the participants' emphases of teaching the NOS.

Participants

Ten Chinese speaking elementary science teachers, four males (Jou, Seung, Yang and Shieu) and seven females (Lu, Dai, Tsu, Tsai, and Wu and Lin), voluntarily participated in this in-service professional development program as a cohort. Those participant teachers were from Kaohsiung and Pingtung counties located in southern Taiwan. The number of classes of their schools ranged from 20 to 99. And there were 30 to 35 students in each class. This group, in terms of major, was typically science education majored except one was non-science education majored. Of the ten participants, three teachers had earned master degrees, others had earned bachelor degrees before entering the program. Among those who had bachelor degrees, six teachers went back to Pingtung Teachers College for master degrees in science education. (Appendix A)

Context

The context within which this investigation conducted was an in-service program that aimed to improve participants' science teaching. The program included three knowledge base components for teaching science: the NOS, transformation of content knowledge and constructivist teaching model. Each part provided the participants with three two- hours activities. The current research focused on improving the participants' understanding of several tenets of the NOS and applying them to a teaching situation. Therefore only this part of the intervention courses was addressed here.

The first part of intervention courses placed emphasis on the NOS and its implications for teaching science in classroom. In particular, the teachers were explicitly taught several aspects of the NOS using activities and the history of the selected scientific theories. Consequently, while the teachers were learning about the NOS, they were also experiencing a model for its classroom implementation. The teachers directly experienced or discussed three different NOS activities. The first one was of the "black-box" variety. In this activity, the teachers were shown a particular phenomenon and asked to infer how it worked. The teachers were then asked to design and construct models that mimiced the behavior of the original phenomenon without ever "seeing" what was inside the "black-box." Ensuing discussions focused on the distinction between observations and inferences, the role of models and theoretical constructs in science, tentative nature of scientific knowledge, and the role of creativity in devising scientific explanations. The second activity was an historical approach to the scientific theories. In this activity, the teachers reflected on the history of certain scientific theories by focusing on significant events that helped them shape the views of the nature of science. The third activity was of the "conceptual-change learning model". In this activity, the teachers inverted a cylinder over a candle burning in a pan of water, they observed the flame soon went out and water rose into the cylinder. They then made an inference based on their observation, and then did the experiment to test their theories. Then, the participants were ask to reflect on their learning experiences and compared to the learning and teaching experiences prior to entering this program.

Following the intervention courses, the teachers were asked to visit classroom demonstrating the constructivist-teaching model and attend the debriefing meetings. Meanwhile, the teachers were asked to implement the constructivist-teaching model in their classroom practices.

Data Collection and Analysis

The version of the NOS questionnaire used in this study was adopted from two studies (Lederman & O'mallet, 1990; Abd-El-Khalick & Lederman, 1998). This questionnaire consisted of seven open-ended items. The aspects of the NOS assessed were the tentative, empirical, creative and subjective nature of science; the role of social and cultural context in science; observation versus inference; and the functions and relationships of theories and laws. The questions and correspondent tenets assessed were indicated as in Appendix B.

Table 1. NOS questionnaire

Tentative	Empirical evidence	Social factor	Personal subjectivity	Human creativity	Human inference	Theory/law difference
Q1	Q4,Q6	Q4,Q7	Q7	Q2,Q5	Q2	Q3

After being double translated into Chinese and corrected by two Chinese-speaking English teachers, this open-ended questionnaire administered to the participant teachers prior to and following the program, to assess their conceptions of the NOS. The questionnaires were not analyzed until the end of the data collection process to avoid biasing the analysis of other data.

In terms of classroom practice, there were two instruments developed in this research. The first one was called the Reflection of Teaching Sequence (ROTS). The aim of this instrument was to evaluate science views reflected from the participant teachers' teaching sequence. There were three categories of science view reflected according the teaching sequence: positivism, inductivism and constructivism. If the teaching sequence started from explanation of the theory, then went to lab activity, it reflected the positivist view of science. If the teaching sequence started from doing observation or lab activity, then discussion followed, it reflected the inductivism view of science. If the teaching sequence started from having students explore their own preconceptions , then went to lab activity, and finally the discussion followed, it reflected the constructivist view constructivism.

Table 2. Views of science imbedded in teaching practice

Teaching sequence	Imbedded views of science
E→A or E→A→E	Positivism
A→E	Inductivism
P→A→E	Constructivism

P: Exploring the students' preconceptions ; E: Explanation of the theory ; A: Lab activity

Another classroom observation instrument, the Levels of Teaching the NOS (LOTNOS), was developed according to the aforementioned researches. The purpose of this checklist was to evaluate how the participant teachers translated several tenets of the NOS into classroom practice. Five tenets of the NOS were involved in this checklist, including tentative nature of scientific claims, empirical evidence for generating scientific theory, human creativity in generating scientific knowledge and social impacts on scientific knowledge. Under each tenet, five levels of assessing teaching the NOS were identified. These levels represented different behavioral approaches to the teaching of the NOS. The LOTNOS definitions were presented in Appendix C.

All participants were asked to submit one unit of classroom videotapes, lesson-plans, and worksheets prior to and following the intervention courses. Before the analysis of classroom practices, two researchers had observed the teaching tapes and practiced the evaluating skills according the two instruments, ROTS and LOTNOS, until they reached 80% consistence. The participant teachers' teaching practices were evaluated by those two researchers according the non-participant classroom observations (classroom tape observation). Finally, all participants were individually interviewed by the end of the program to validate their responses to the NOS questionnaire and generate in-depth understanding of their views of the NOS, teaching the NOS, as well as their knowledge base of teaching the NOS.

Analysis of the questionnaire was postponed until the completion of implementing the constructivist teaching model to avoid biasing the analysis of other data sources. The interview transcripts were analyzed to validate the participants' responses to the NOS questionnaire, to elucidate how the teachers taught the NOS, their knowledge base of teaching the NOS, and their concerns of teaching science. Data from interviews were used to generate categories that were checked against confirmatory or other contradictory evidence in the data and modified accordingly. Several rounds of the above procedures were conducted to satisfactorily reduce and organize the data.

Findings

The Intervention Had Little Impacts on the Teachers' Views of the NOS

Before the professional development program, most participant teachers showed proper understanding of three tenets of the NOS, including tentative, empirical nature of science, and the role of personal impacts in generating scientific knowledge. Except one teacher (Tzu), nine of ten teachers ignored social impacts on the science. After the intervention, among those nine teachers, only one teacher (Jou) hold a better understanding of social nature of science. The above findings were derived from the participants' responses to the NOS questionnaire (Appendix D) and interviews. The teacher (Jou) showed his better understanding of the social impacts on the construction of scientific knowledge by comparing his responses to the NOS questionnaire prior to and after the intervention like:

> "With the limited data, it was impossible to lead the same conclusion. If scientists accumulated more data in the future, they would got the same conclusion."
>
> (Jou,, pretest of the NOS #7)
>
> "Scientific knowledge was constructed by science community. Different science community used different theory to make explanation. Therefore there was no consensus among their conclusions. "
>
> (Jou, post-test of the NOS #7)

The teachers of the current research showed similar conceptions about the NOS to the US teachers reported by Abd-El-Khalick et.al. in 1998, and better understanding about the NOS than those teachers of the earlier researches (Behnke, 1961; Carey and Stauss, 1970).

The Intervention Improved Some Teachers' View of Teaching the NOS

Prior to this program, except one teacher (Wu) responded that she did not teach the NOS, others responded that they did teach the NOS implicitly through the whole teaching process, such as making observations, and doing experiments. One of those teachers expressed her blurring conceptions between the NOS and the process of science as following:

> "In fact, you taught the NOS through lab activities which included scientific method, experimentation, and attitude. I think the NOS is a concept that covers method, attitude and process."
>
> (Dai, interview before intervention)

After this program, the teacher (Wu) who did not think there was a need to teach the NOS before had changed her view of teaching the NOS:

> "Before enrolling in this program, I though it was difficult to teach the NOS because I had no experience and I taught low-grade kids. I did not know how to teach the NOS. After watching several classroom demonstrations, I feel it is not so difficult as I thought before. Now I know how to guide kids to learn science and clarify some aspects of the NOS at the proper point."
>
> (Wu, interview after the intervention)

Some teachers got a better understanding of teaching the NOS. Compared to their responses prior to the intervention, they made better descriptions about how they taught the NOS while teaching science. However, they claimed that they still taught the NOS implicitly. Among ten teachers, three teachers (Yang, Shiu and Dai) responded that they taught the social, subjective, creative, and empirical-based nature of science in their classroom practices implicitly. They also admitted that they did not make it clear to kids. Two teachers (Dai and Shui) described how they taught the NOS like:

> "Yes, I taught it (the NOS). In my teaching process, I provided a context in which they felt the tentative nature of science as they got different answers, and I didn't say which one was the right answer. When they told peers how they got their answers through their experiments, they learned that the empirical evidence is important for scientific claims.
>
> (Dai, interview after the intervention)
>
> "The conceptions (of the NOS) were imbedded in my teaching. In fact, the classroom was a small society. When they communicated or shared their ideas with peers, they learned the social factors of the NOS. When they learned the movement of the earth, they learned the theory must changed while encountering the incompatible evidence. In terms of teaching the creative nature of the NOS, I asked students to think out ways to prove their hypothesis. They needed to design they own experiments. That was not passive learning and the NOS was imbedded in the learning process."
>
> (Shui, interview after intervention)

Other teachers (n=7) did not describe how they taught the NOS specifically. They still blurred the conception of the NOS with the process of scientific exploration like:

> " I let students discuss how to find out what caused the ghost fire. Then they observed (the ghost) and recorded (the data). Finally, they shared and discussed their findings with other students."
>
> (Jou, interview after intervention)

The aforementioned data showed that the intervention had impacts on some teachers' statements of translating the conceptions of the NOS into classroom practices with different levels of recognition. However, still some did not include teaching the NOS in their pedagogical thoughts.

The Intervention Had Impacts on Some Teachers' Teaching Practice

There were two instruments used to evaluate the teachers' classroom practices. According to the analysis by using the ROTS instrument, all participants' teaching sequences inclined to the inductivist view prior to the intervention. Among ten participants, only one teacher (Seung) whose one session of teaching inclined to the view of positivism whilst he was teaching the theory of lever, and three teachers' (Lu, Yang and Tsai) one session of teaching inclined to the view of constructivism while they were asking students to design experiments or draw city maps based on their own ideas. According to the analysis by using the LOTNOS checklist, all participants, including three teachers (Lu, Yang and Tsai) whose teaching behaviors reflected the creative and social nature of the NOS, revealed the empirical evidence and human inference of the NOS implicitly.

The following statement was Seung's one teaching session of "the principle of the lever" before the intervention:

#1. Seung posted a picture on the blackboard. The picture showed how ancient Egyptians lifted huge rocks up to build a pyramid.

#2. Seung told students that ancient Egyptians used the theory of lever to lift the huge rock up.

#3. Seung posted another picture of the first-class lever on the blackboard and wrote three terms, as applied force, load, pivot point, with arrows pointing to the right position of the lever. Then Seung explained those terms to students.

#4. Seung posted three pictures on the blackboard that represented three different positions of pivot point on the stick.

#5. Seung had students do lab activities according the above three settings.

#6. After that hands-on activities, Seung led the class discussion that focused on the effect of the position of the pivot point on the applied force.

(Seung, classroom observation before the intervention)

The above Seung's teaching practice inclined to reflect the view of positivism. Seung introduced students the principle of the lever by integrating the event of the Egyptian pyramid (#1,#2,#3), then asked students do experiment to prove the theory (#4,#5,#6). The Seung's teaching behaviors revealed empirical evidence and human inference of the NOS.

After the intervention, the data of participants' ROTS showed that three teachers (Jou, Seung and Shiu) had not changed their previous teaching sequence that inclined to the view of empiricism. Others (n=7) had changed part of their teaching sessions to reveal the view of constructivism. According to the analysis by using the LOTNOS checklist, all participants' teaching behaviors had changed. In addition to their previous teaching behaviors revealing the empirical and inferential aspects of the NOS, their teaching behaviors revealed creative (n=8) and social (n=10) aspects of the NOS. But the tentative nature of science was not revealed in all participants' teaching practices. An example of Seung's one session of teaching " lenses" was like:

#1. Seung projected the ghost fire from a black box to the black board of the classroom.

#2. Seung asked students to make the similar image by using a match, a candle, a magnifying glass and a paper screen.

#3. Students were working in groups of six to create the image.

#4. Seung asked students to find out how to make a clear image (by moving the screen or adjusting the distance between the candle and lens).

#5. Seung asked students to describe the characteristics of the image (the image is upside down).

#6. Seung asked students to raise the empirical evidence (or experiment) to explain why the image is upside down to peers during the class discussion.

(Seung, classroom observation after the intervention)

Seung had students observed the phenomenon through a black box and design the experiment (#1,#2,#3,#4), then asked students to raise empirical evident to show their descriptions of the image were reasonable. Seung's teaching session inclined to the view of inductivism. In addition to the empirical evidence (#5) and human inferential aspect (#6) of the NOS, Seung's teaching behaviors also revealed the creative (#2,#4,#6) and social (#3,#6) aspects of the NOS. Seung mentioned that his idea of black box was from the learning activity of the intervention:

> "The activity of black box was really a shock to me. In that activity, all of us tried to figure out what caused the blue water flowing out. Meanwhile, I was thinking I could also have my students design different experiments. Before involving in this program, I felt it would take me a lot of time and my students might not be smart enough to do it. Not until I tried it, did I find that my students not only could design the experiments, they seemed to be more interested in learning science than before."

(Seung, interview after the intervention)

Another example was Yang's one session of teaching, "the oxygen is in the air" as following:

#1. Yang asked students to discuss about the question "Where is oxygen?" in group.
#2. Yang asked each group reporter to stand up and tell their peers where oxygen is.
#3. Yang encouraged students to raise their suspicions to the reports.
#4. Yang sorted all statements into two statements: (1) the air has oxygen only; (2) the air has oxygen and other gases.
#5. Yang asked students to design the experiment to find out the amount of oxygen in the air.
#6. Group discussion and then class discussion.
#7. Students conducted the experiment. (They covered the burning candle, which was standing on a water pan, with a beaker and watched the raise of water level inside the beaker).
#8. Students observed the results of the experiment and made reference in group.
#9. During class discussion, Yang encouraged students to elaborate their explanations and suspicions.
#10.Yang summarized the discussion and concluded that the air has oxygen and other gases.

(Yang, classroom observation after the intervention)

In Yang's classroom, students elaborated their thinking before experiment (#1,#2) and constructed explanation based on their observation (#8,#9,#10). Yang's teaching practice inclined to the view of constructivism. Beside the empirical evidence and human inferential aspects of the NOS (#8,#9), Yang's teaching behaviors revealed the creative (#5) and social aspects (#1,#2,#3,#6,#9) of the NOS. When asking about how the program affected his teaching, he replied:

> "The experience of the first activity (black box) affected my teaching a lot. I had never thought about my teaching. Since then my teaching was changing to the side of constructivist teaching."
>
> (Yang, interview after the intervention)

In sum, even though the participants did not include teaching the NOS in their pedagogical thoughts, seven of ten participants had changed part of their teaching practices from the inductivism to the constructivism, and their teaching behaviors revealed teaching more aspects of the NOS implicitly, including the human creativity and social aspects.

The Teachers' Beliefs and Knowledge Base about Teaching the NOS

According to the teachers' responses to the question about the aims of science learning, we found that the intervention did not change much of the teachers' thinking about science teaching. There were several beliefs that guided the teachers' classroom practices, such as learning content knowledge (pre-intervention, n=6; post intervention, n=4), scientific process, skills and attitude (pre-intervention, n=4; post-intervention, n=3), problem-solving (pre-intervention, n=4; post intervention, n=6)

Although some participants (n=6) insisted that the purposes of scientific experiment was to help students learn problem solving skills and attitude, others (n=4, Lu, Dai, Tsai, Wu) had changed their views about the purposes of scientific experiment to be more consistent with current views of constructivist theory:

> "Before attending this program, I thought the purpose of scientific experiment was to provide students experiences of sharing the experience and building team spirit through solving the problems. Now I don't think so. I don't think the purpose of scientific experiment was to share the experience. The purpose of the experiment is to solve the problem. That is a process."
>
> (Lu, interview after intervention).
>
> "Before involving in this program, I thought the experiment was to provide students experience. Now I think the purpose of the experiment was for students to test their thinking. When you got a problem, you felt curious and you might have a reason to explain it. So you need to do experiment to prove your thinking."
>
> (Tsai, interview after intervention)

The above analysis indicated that the intervention had different impacts on the teachers' beliefs of science teaching. For some teachers, it was difficult to change their belief, and for others, only part of their beliefs can be changed. In this research, the intervention only lasted for one year. It might take more than one year to find the change of teachers' belief.

In order to transform the NOS into classroom practice, teachers should have adequate understanding of the development of the scientific concept (Anderson, 1987). Although the program provided the participants several articles and the history of some scientific concepts, they still lacked a proper knowledge base of teaching the development of knowledge:

> "As for the history of science, I am not familiar with it. I only know some of it I guess. Therefore, I did not embed the development of scientific concepts in my teaching. The main reason is that I was not taught the NOS in that way. Besides, I do not know how to get that information either. If we were asked to teach science with the history of science, it might burden our teaching load."
>
> (Dai, interview after intervention)

The above statement showed that the teacher did not feel having enough knowledge about the history of science. And there is no acceptable resources or activities teaching the NOS for elementary students. In order to transform the NOS into classroom, the teachers need more examples and resources. The aforementioned assumption needs extensive exploration.

Conclusion

In this study, we found that of 10 participants the majority possessed views of several aspects of the NOS before involving in the program. However, they could not clarity the ways of teaching the NOS. After the intervention, some of them described how they taught several aspects of the NOS implicitly.

In terms of classroom practices, most participants' teaching inclined to the view of inductivism, and revealed the empirical and inferential aspects of the NOS prior to the intervention. After the intervention, seven out of ten teachers embedded the view of constructuctivism in their classroom practices, in which the creative and social aspects of the NOS were revealed. As to the emphasis of teaching science, the participants did not place teaching the NOS as important as other aspects. The above findings explained the complex relationship between understanding the NOS and teaching the NOS. There were several constraints for teaching the NOS:

1. The teachers lacked knowledge about the development of the scientific concepts associated with their teaching content.
2. The teachers lacked proper examples of classroom strategies as examples of translating the aspects of the NOS in classroom.

In order to overcome the above constraints, extensive efforts should be made, such as:

1. Helping teachers integrate the development of the scientific concepts to their teaching content in which students could understand how scientific knowledge generated.
2. In addition to the constructivist teaching approach, we need to provide teachers proper examples of classroom strategies that allow them and children to explore and investigate the tentative and other aspects of the NOS through unplanned, spontaneous incidents or planned teaching.

The above suggestions need extensive studies.

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APPENDIX A

Background information about teacher participants

1.Personnel data

ID	Gender	Major	Teaching years	Science teaching years	Education
Jou	M	Sience	15	10	B. A. & Graduate student
Lu	F	Science	15	10	B. A. & Graduate student
Sueng	M	Non-science	20	11	B. A.
Dai	F	Science	10	9	M. A.
Yang	M	Science	6	1	B. A. & Graduate student
Tzu	F	Science	7	1	M. A.
Shiu	M	Science	7	4	M. A.
Tsai	F	Science	4	4	B. A. & Graduate student
Wu	F	Science	11	6.5	B. A. & Graduate student
Lin	F	Science	4	4	B. A. & Graduate student

2. Teaching context

ID	Teaching status	Teaching graders	School location	School size (total number of class)
Jou	Science teacher	5,6	Urban	38
Lu	Science teacher	6	Urban	38
Sueng	Science teacher	5	Urban	60
Dai	Science teacher	4,6	Suburban	24
Yang	Classroom teacher	4	Suburban	20
Tzu	Classroom teacher	4	Urban	47
Shiu	Science teacher	6	Urban	99
Tsai	Classroom teacher	3	Surburban	37
Wu	Classroom teacher	2	Urban	67
Lin	Classroom teacher	2	Suburban	27

3. Context and participants

Context and background		Number of participants
School size (classes)	20-30	3
	31-50	4
	51-100	3
Class size (students number)	30-45	10
Teaching status	Science teacher	5
	Classroom teacher	5
Teaching grader	4-6	7
	1-3	3
Participant Teachers' education	B.D.	7
	M.D.	3
Participant Teachers' Majors	Science	9
	Non-science	1

APPENDIX B

Questions and assessing tenets of the NOS

Questions	Assessing tenets of the NOS
1. After scientists have developed a theory (e.g., atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.	1. Assessing understandings of **the tentative nature of scientific claims**, why these claims change.
2. What does an atom look like? How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?	1. Assessing understandings of **the role of human inference and creativity in science**, 2. Assessing understandings of **the role of models in science**.
3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.	1. Assessing conception about theories and laws.
4. How are science and art similar? How are they different?	1. Assessing understandings of **the role of creativity and imagination in science**, the necessity of **empirical evidence** in generating scientific knowledge, and the **cultural and social embedded ness** of science.
5. Scientists perform experiments investigations when trying to solve problems. Other than the planning and design of these experiments/ investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.	1. Assessing understandings of the role of **human creativity and imagination** in science and the phases at which students believe that these play a role.
6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.	1. Assessing understandings of the role of **empirical evidence** in generating scientific knowledge.
7. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?	1. Assessing understandings of the factors that affect scientists' work. Such factors range from **personal** preferences and bias to differing theoretical commitments to **social and cultural factors**.

APPENDIX C

Level of teaching the NOS (LOTNOS)
Classroom observation checklist (teaching the NOS)

Chapter title：	**Activity title：**	**Observer：** **Teacher name：** **date：**
Tenets of the NOS	**Descriptions of teaching**	**Brief description of Activities**
1. Tentative Nature of Scientific Claims	☐ Not taught ☐ Being taught directly through explanation. ☐ Being taught through the historical process. ☐ Being taught implicitly through self-awareness of conceptual change. ☐ Being taught implicitly through relating student's self-awareness of conceptual change to the tentative nature of scientific knowledge.	
2. Empirical evidence for generating scientific knowledge	☐ Not taught. ☐ Being taught directly through explanation. ☐ Being taught through example、evidence or empirical data. ☐ Being taught through the historical process. ☐ Being taught implicitly through lab activities, making explanation based on the empirical data. ☐ Being taught explicitly through additional clarification to students' experience of scientific process.	
3. Human inference in generating scientific theory	☐ Not taught ☐ Being taught directly through explanation. ☐ Being taught indirectly though the historical story. ☐ Being taught implicitly through making inference based on the empirical data. ☐ Being taught explicitly through additional clarification after lab activities and making inference based on the empirical data.	
4. Human creativity in generating scientific knowledge	☐ Not taught. ☐ Being taught directly through explanation. ☐ Being taught indirectly though the historical process. ☐ Being taught implicitly through facilitating context in which students need to think creatively in designing experiments, making inferences and explanations. ☐ Being taught explicitly through additional clarification after students' experience of lab activities and thinking process.	
5. Social impacts on scientific knowledge	☐ Not taught. ☐ Being taught directly through explanation. ☐ Being taught indirectly though the historical process. ☐ Being taught implicitly through facilitating the context in which students share their explanations with their teacher and peers. Furthermore, other students need to judge peer's ideas critically. ☐ Being taught explicitly through additional clarification after students experience the process of social recognition.	

APPENDIX D

The teachers' responses to the NOS questionnaire (Pre-post intervention)

1. Tentative nature of scientific claims (Q#1)

	Jou	Lu	Seung	Dai	Yang	Tzu	Shiu	Tsai	Wu	Lin
Pre-intervention	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Post-intervention	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

2. Empirical evidence of generating scientific claims (Q4, Q6)

	Jou	Lu	Seung	Dai	Yang	Tzu	Shiu	Tsai	Wu	Lin
Pre-intervention	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Post-intervention	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

3. Human inference of scientific claims (Q2)

	Jou	Lu	Seung	Dai	Yang	Tzu	Shiu	Tsai	Wu	Lin
Pre-intervention	Y	N	N	Y	N	Y	Y	Y	N	Y
Post-intervention	Y	N	N	Y	Y	Y	Y	Y	Y	Y

4. Personal impacts (including subjectivity and creativity) on scientific claims (Q7, Q4, Q5)

	Jou	Lu	Seung	Dai	Yang	Tzu	Shiu	Tsai	Wu	Lin
Pre-intervention	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Post-intervention	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

5. Social factors in generating scientific theory (Q4, Q7)

	Jou	Lu	Seung	Dai	Yang	Tzu	Shiu	Tsai	Wu	Lin
Pre-intervention	N	N	N	N	N	Y	N	N	N	N
Post-intervention	Y	N	N	N	N	Y	N	N	N	N

6.Conceptions about the difference between theory and law (Q3)

	Jou	Lu	Seung	Dai	Yang	Tzu	Shiu	Tsai	Wu	Lin
Pre-intervention	N	N	N	Y	N	N	N	N	N	N
Post-intervention	N	N	N	Y	N	N	N	N	N	N

APPENDIX E

Teaching units, inclined views of science (VoS) and the aspects of the NOS (ANOS) revealed in the participant teachers' teaching practices

(before and after the intervention)

ID		Before the intervention	After the intervention
Jou	**Unit**	**Star watching**	**Lenses**
	VoS	Inductivist view	Inductivist view
	ANOS	EV; HI	EV; HI; S
Lu	**Unit**	**Map**	**Inheritance**
	VoS	Inductivist view and constructivist view	Inductivist view and constructivist view
	ANOS	EV; HI; C; S;	EV; HI; C; S
Sueng	**Unit**	**The principle of the lever**	**Lenses**
	VoS	Inductivist view and positivist view	Inductivist view
	ANOS	EV; HI	EV; HI; S
Dai	**Unit**	**Acids and Bases**	O2 & CO2
	VoS	Inductivist view	Inductivist view and constructivist view
	ANOS	EV; HI;	EV; HI; S;C
Yang	**Unit**	**Water movement in plant body**	**O_2 & CO_2**
	VoS	Inductivist view and constructivist view	Inductivist view and constructivist view
	ANOS	EV; HI; C; S;	EV; HI; C; S
Tzu	**Unit**	**Dissolution**	**O_2 & CO_2**
	VoS	Inductivist view	Inductivist view and constructivist view
	ANOS	EV; HI	EV; HI; C; S
Shiu	**Unit**	**Acids and Bases**	**Rust on iron wool**
	VoS	Inductivist view	Inductivist view
	ANOS	EV; HI	EV; HI; C; S
Tsai	**Unit**	**Heat**	**Weight and scale**
	VoS	Inductivist view and constructivist view	Inductivist view and constructivist view
	ANOS	EV; HI; C; S;	EV; HI; C; S
Wu	**Unit**	**Electricity**	**Lemon juice**
	VoS	Inductivist view	Inductivist view and constructivist view
	ANOS	EV; HI	EV; HI; C; S
Lin	**Unit**	**Electricity**	**Lemon juice**
	VoS	Inductivist view	Inductivist view and constructivist view
	ANOS	EV; HI	EV; HI; C; S

views of science (VoS); aspects of the NOS (ANOS) ; T: tentative aspect; EV: empirical evidence; HI: human inference; S: Social aspects; C: Creativity.

APPENDIX F

The participant teachers' views about science teaching and scientific experiment

		Pre intervention	Post intervention
Aims of science learning	Content knowledge	6	4
	Scientific process skills	4	3
	Scientific attitude	4	3
	Problem solving	4	6
Purposes of experiment	Concept learning	3	2
	To learn scientific attitude and skills	2	2
	Problem solving	6	6
	To prove students' thinking or hypothesis	1	4

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