KNOWLEDGE AND SKILLS THAT SCIENCE TEACHERS NEED FOR TEACHING THE NATURE OF SCIENCE

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ABSTRACT

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Nature of science (NOS) has long been a highly valued element of science education, but it remains largely ignored in science classrooms despite decades of efforts in promoting it. Past research mostly focuses on curricular efforts and NOS understanding of teachers and students to the exclusion of in depth examination of NOS teaching in actual classrooms. The studies targeting NOS teaching, however, often put heavy emphasis on the intentions and beliefs of teachers to account for whether or not NOS aspects are addressed in the classrooms. These types of studies still treat NOS teaching as a black box without addressing the complex interplays between teachers and students in class, and also fail to address the issues pertaining to the competence of teachers in NOS teaching. This study seeks to delineate and understand the complex dynamics of NOS teaching in actual classroom contexts in order to shed light on the knowledge and skills that science teachers need to teach NOS. The study employed a multiple case study design, examining in depth the NOS teaching attempts of eight science teachers in Hong Kong. Data were collected mainly through class observations, interviews, and analysis of teaching plans. The NOS understandings and constructivist pedagogy of the teachers were assessed with quantitative instruments. A framework for the key characteristics of NOS teaching is established based on the literature and empirical findings of this study. Three knowledge bases are found connected with these characteristics: knowledge of NOS, pedagogical knowledge and skills to teach NOS in a constructivist and dialogic manner, and knowledge of the contexts for NOS teaching, such as history of science. The implications of the findings to teacher training and curriculum development pertinent to NOS were discussed.

To my beloved wife, Jade, and sons, Jack and Mike

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Key words

Nature of science, NOS, NOS teaching, teaching about nature of science, pedagogical content knowledge

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Addenda consisting of one DVD–ROM, which contains electronic files of:

- teaching transcripts of the teachers
- teaching plans and materials for the lessons
- self-reflections of the teachers
- SUSSI questionnaires completed by the teachers
- Evaluation of the learning outcomes of students
- A detailed analysis of the lessons of individual teachers

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Abbreviations

NOS: Nature of science

PCK: Pedagogical content knowledge

SSIs: Socioscientific issues

Abbreviations of computer files in the DVD ROM:

- Pseudonyms of the eight teachers: CYT, NWY, LKY, PHF, MPY, WTY, WYC, KWM
- PHF-1: The first attempt at NOS teaching of the teacher if more than one lesson of the teacher were studied.
- PHF-R: The self-reflection of the teacher in the pseudonym of PHF
- PHF-T: The transcript of the NOS teaching of the teacher
- PHF-T, 60: The excerpt numbered 60 of teaching transcript was quoted in the text
- PHF-I: The interview of the teacher
- PHF-TP: The teaching plan of the teacher
- PHF-TM: The teaching materials of the lesson, usually in form of powerpoint slides
- PHF-SUSSI: The responses of the teacher in SUSSI
- PHF- A: Detailed analysis of the lesson of the teacher
- PHF-LO: Evaluation of the learning outcomes of students by the teacher

Chapter One

Introduction

This chapter gives a general outline of the whole study. First, the problems that this study deals with are discussed, drawing on the history of research on NOS and its teaching to explain why NOS teaching is an under-researched area. Then, the purposes and specific research questions of the study are introduced. The significance of the study for theory and practice is also discussed. Finally, the methodology of the study is outlined.

THE PROBLEMS

The Nature of Science (NOS) generally refers to the issues as to what science is, how science works, what the epistemological and ontological underpinnings of science are, how scientists function as a social institution, and what the relationship is between science and society (Abd-El-Khalick, Bell, & Lederman, 1998; Clough & Olson, 2008). Understanding NOS is widely recognized by science educators as one of the central goals of science education (Abd-El-Khalick et al., 1998; Duschl, 1994; Lederman, 2007; McComas, Clough, & Almazroa, 1998). This emphasis is reflected in major K-12 science curriculum reform efforts, including those of the National Science Education Standards of the United States (National Research Council [NRC], 1996) and the National Curriculum of the United Kingdom (Department of Education, 1995). Despite nearly fifty years of efforts in promoting NOS teaching and learning, the outcomes appear disappointing- most science teachers and students have “inadequate” understandings of NOS (Lederman, 2007, p. 869). Thus, science educators ask: What made all the efforts in promoting this valued goal of science education generally futile? What was missed, or what was insufficient? Some even start to doubt whether this goal is justified because nature of science teaching promotes skepticism about and disbelief in science (Winchester, 1993).

One of the problems with NOS teaching stems from what constitutes an "adequate" understanding of NOS for precollege students. There is a heated debate over what the nature of science is among science educators, philosophers of science, sociologists of science, historians of science, and scientists. To date, the issues not only remain unresolved, but have become "both more contentious and more pressing than they were previously" (Matthews, 1998, p. 162). Science educators contend that the unsettled philosophical issues such as realism/instrumentalism are largely irrelevant and inaccessible to K-12 students. Science educators propose lists of *NOS tenets* at higher levels of generality, which are deemed appropriate and relevant to pre-college students, and they claim that a consensus on these tenets has already been reached among science educators and in reform documents (American Association for the Advancement of Science [AAAS], 1993; Abd-El-Khalick et al., 1998; Lederman, 2007; McComas et al., 1998; McComas & Olson, 1998 ; NRC, 1996; Smith, Lederman, Bell, McComas, & Clough, 1997). Hence, although there are still disagreements with the oversimplified NOS tenets (Alters, 1997a; Duschl, 2006), the issue of what aspects of NOS should be taught to precollege students has been mostly resolved. However, the NOS tenets are often misunderstood by teachers and used in NOS assessment instruments as the mere outcomes of NOS teaching (Clough, 2005). Consequently, the teaching and assessment of NOS tend to emphasize the general understanding of NOS to the exclusion of contextual nuances (Elby & Hammer, 2001, p. 555).

In view of students' inadequate understanding of NOS, a line of research has focused on improving the NOS understanding of the precollege students (e.g., Bell, Blair, Crawford, & Lederman, 2003; Khishfe & Abd-El-Khalick, 2002; Liu & Lederman, 2002; Moss, 2001). These studies are typically in a pretest-posttest design, using the standardized NOS instruments with/without interviews. Gains in students' understanding of NOS are then attributed to the interventions, such as the explicit and reflective approach, scientific inquiry activities, historical case studies and apprenticeship with scientists. These studies, however, follow an input-output research design that treats classroom teaching as a black box (Lederman, 2007, p. 869). Aside from general teaching approaches, the question of how teachers teach NOS in classes remains largely unexplored.

Parallel to the studies on improving the NOS conceptions of students, another line of research focuses on science teachers, which are also found having "inadequate" NOS understanding and considered as a significant barrier to students' learning of NOS. This has led to a substantial number of studies devoted to improving the NOS conceptions of in-service and pre-service science teachers (e.g. Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Lin & Chen, 2002; Schwartz, Lederman, & Crawford, 2004). These studies have an "unstated" assumption that the improvement of teachers' NOS conceptions would bring about corresponding improvement to that of students, but this assumption is largely "untested" (Lederman, 2007, p. 852). Research generally supports that the NOS conceptions of science teachers could be improved by interventions using historical and/or explicit, reflective approach (Lederman, 2007, p.852), but the subsequent impact on students has not been realized as expected.

Lederman (2007) contends that "several decades of research on NOS focused on students and teacher characteristics or curriculum development to the exclusion of any direct focus on *actual classroom practice* and/or *teacher behaviors*" (p. 853). Some NOS researchers have started to shift their attention to teacher behavior in classroom. One of the research directions is the examination of the relationship between the NOS understanding and classroom practices of teachers, and the factors that mediate this *translation* (Abd-El-Khalick et al., 1998; Brickhouse, 1990; Lederman, 1999; Schwartz & Lederman, 2002). A general conclusion in this line of research is that the NOS conceptions of science teachers do not automatically and necessarily *translate* into teaching practices, even among teachers that have "informed" NOS conceptions (e.g., Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, 1999; Lederman & Zeidler, 1987). A number of contextual variables have been identified to mediate the instructional planning and actual practices of teachers regarding NOS, including institutional constraints, pressure to cover the subject matter, concerns for classroom management and student abilities, perceived student needs, and lack of confidence and suitable resources to teach NOS (Abd-El-Khalick et al., 1998; Brickhouse & Bodner, 1992; Lederman, 1995). These studies seem to attribute the major impediment in NOS teaching to the *instructional intentions* of teachers, which are mediated by a host of personal beliefs and institutional constraints, while neglecting a hidden but significant issue: *Are the teachers really capable of teaching NOS effectively regardless of their instructional intentions?* Lederman (1999) found that even the teachers with maximum flexibility in deciding what to teach do not significantly incorporate NOS aspects in their classes. Moreover, given the central role of NOS, which is unambiguously emphasized in many international science curriculum reform documents (AAAS, 1993; NRC, 1996) and local science curricula (Curriculum Development Council [CDC] & Hong Kong Examination and Assessment Authority [HKEAA], 2007a, 2007b), is it true that the attempts of teachers to teach NOS is opposed by schools, students, parents, and even their own colleagues? Are the external constraints being exacerbated as excuses for the lack of interest among teachers to include NOS in their lessons? Furthermore, does the lack of interest among teachers stem from their *inability* to teach NOS effectively? A few studies have shown that even teachers that have been trained adequately, have "informed" NOS conceptions, and have strong intentions to teach NOS are still unable to effectively address NOS aspects in class (Abd-El-Khalick et al., 1998; Akerson & Abd-El-Khalick, 2003). This shows that, in NOS teaching, the instructional intentions of teachers are probably secondary to their abilities to teach NOS, which appears to be the primary barrier preventing the actualization of NOS teaching in classrooms. The teachers' lack of competence naturally leads to failure in teaching NOS, which in turn causes teachers to blame a host of external factors and go as far as to question the value of NOS. Although the relationships between intentions and abilities are likely to be reciprocal, abilities are likely at the heart of the deadlock that can start a positive feedback cycle to improve the intentions of teachers in teaching NOS.

In exploring the abilities required to effectively teach NOS, an obvious first step is to examine how NOS is actually taught in classrooms. However, previous research on NOS teaching practices seems to have headed toward a wrong direction. Most of the studies (Abd-El-Khalick et al., 1998; Brickhouse, 1990; Lederman, 1999; Schwartz & Lederman, 2002) basically follow the following design: (1) assess the NOS understanding of teachers using NOS instruments with/without interviews; (2) examine whether NOS aspects are addressed by teachers in the class; (3) attribute the teaching practices to the NOS conceptions of teachers, as well as a host of external constraints and personal beliefs expressed by teachers during interviews. In such design, the practice of NOS teaching is treated as a *black box* in the sense that the researchers have no interest in examining and describing in detail how teachers address NOS aspects in class, in what ways the teaching is effective or not, and how students respond in class. They are simply concerned with whether or not NOS aspects are addressed in class, leaving the complex interactions in the classroom largely unexplored. There are only a few empirical studies that examine in detail the complex process of NOS teaching in actual classroom (Bartholomew, Osborne, & Ratcliffe, 2004; Schwartz, & Lederman, 2002; Ryder and Leach, 2008). Without this kind of studies, the problems of teachers' inability to teach NOS effectively would be perennial.

Related to the above problem is what counts as an effective way to teach NOS. The two most commonly cited approaches to NOS teaching are the *explicit, reflective approach* and the *implicit approach* (Abd-El-Khalick & Lederman, 2000a). The implicit approach refers to hands-on, laboratory-based inquiry activities without explicitly pointing out the aspects of NOS in the process (e.g. Haukoos & Penick, 1985; Riley, 1979; Spears & Zollman, 1977). On the other hand, the explicit, reflective approach emphasizes the "purposeful instruction of NOS through discussion, guided reflection, and specific questioning in the context of classroom science activities" (Schwartz & Lederman, 2002, p. 207). Although the explicit, reflective approach is empirically supported to be more effective than the implicit approach in enhancing the NOS understanding of both students and teachers (Abd-El-Khalick & Lederman, 2000a, p. 692; Lederman, 2007, p. 869), the meaning of this approach in actual classroom teaching is far from clear, especially with regard to what "reflective" means. Aside from the general approach, NOS aspects have to be taught in various contexts, such as historical cases of science, scientific inquiries, socioscientific issues, and content-free NOS activities. The effectiveness of these contexts has been widely studied (e.g. Abd-El-Khalick, 2005; Khishfe & Abd-El-Khalick, 2002; Lin & Chen, 2002), but how these contexts are used to explicitly address NOS aspects in actual classroom has rarely been examined in depth. On the other hand, apart from empirical studies, effective NOS teaching has to draw on models and perspectives from effective teaching, in general and effective science teaching, in particular. For instance, Clough (2006) conceptualized effective NOS instruction from the perspectives of conceptual change. However, there seems to be a lack of comprehensive framework that draws upon both empirical findings and theoretical models to inform researchers and teachers on what effective NOS teaching means.

Another issue pertaining to NOS teaching is the failure of teachers - despite their "informed" NOS conceptions as assessed by NOS instruments - to effectively address and represent NOS aspects in classrooms. Some conclude that NOS understanding is a necessary but not sufficient condition for effective NOS teaching, and what has been missed is the pedagogical content knowledge (PCK) for NOS (Abd-El-Khalick & Lederman, 2000a). If PCK is broadly defined as "the transformation of subject matter knowledge into forms accessible to the students being taught" (Geddis, 1993, p. 675), such a "transformation" is on the top of the mastery of subject matter knowledge. However, some studies have revealed that teachers simply fail to recognize and accurately explicate the NOS aspects in teaching, let alone represent them effectively (Akerson & Abd-El-Khalick, 2003; Lederman, 1999). On the surface, the problem pertains more to the NOS understanding of teachers than the pedagogical transformation of NOS aspects.

The question that follows dwells on why the "informed" NOS understanding of teachers, as assessed by NOS instruments, is inadequate for effective NOS teaching. Given the criticisms on NOS instruments (Lederman, Wade, & Bell, 1998), it is natural to question the validity of such "informed" conceptions as assessed by NOS instruments. It is easy to agree or disagree on the NOS statements in the assessment instruments, but it is another thing to explicate accurately NOS aspects in specific contexts during teaching. This points to some more deeply rooted issues regarding not only the assessment of NOS, but also the teaching and learning of NOS: *Are NOS aspects universal or specific to contexts and disciplines? Does a person hold unique views of NOS that are consistent across contexts, or varying NOS views that are context dependent* (Leach, 2006)? For instance, some biologists have put forward criticisms that some NOS aspects are derived based on the studies of physical sciences, such as the scientific paradigms proposed by Kuhn (1996), which are not applicable to biological sciences (Mayr, 1998; Wolpert, 1994). If NOS aspects are largely context bound as Clough (2005) contended, then the effective teaching of NOS requires teachers to successfully *transfer* general NOS conceptions that they have acquired from NOS teaching courses to specific contexts required in their own classroom. Although NOS teaching courses may address aspects of NOS in some contexts, the contexts are often limited and not in exact correspondence with what teachers use in their own classrooms. Hence, there is always a *transfer problem* in the NOS conceptions of a teacher for effective NOS teaching. The failure to transfer general NOS understanding to the contexts of teaching probably explains why teachers, even having “informed” NOS understanding, are still unable to effectively teach NOS in class. However, this transfer problem has not been substantially examined in the NOS literature.

PURPOSE OF THE STUDY

Given the above problems associated with both the research and practice of NOS teaching, this study aims to conduct an in-depth exploration on how secondary science teachers in Hong Kong teach NOS in classrooms. The NOS teaching is described in detail in relation to what the general teaching approach is, how NOS aspects are addressed and represented in contexts, what communicative approaches teachers take, and what the responses of students are. By comparing the NOS conceptions that teachers explicate and represent in class with those assessed by NOS instruments, the study also sheds light on the gap between the general and contextual understanding of NOS among teachers.

In addition to describing classroom teaching in detail, this study also seeks to evaluate the NOS teaching through examining its process from a theoretical framework drawn from the literature, rather than by empirical assessment of learning outcomes as in many other studies. To serve this, a framework for the characterization of NOS teaching is thus needed, but it is absent in the extant NOS literature. Many studies only focus on a particular aspect of NOS teaching, such as the explicit/implicit approaches, contexts, or classroom talk, whereas some only judge "successful" NOS teaching by "the identification of attempts to plan for and teach NOS explicitly" (Schwartz & Lederman, 2002, p. 229). Therefore, one important aim of this study is to draw on relevant research findings and teaching models to construct an initial framework to characterize NOS teaching. Particular emphasis is placed on the personal and social constructivist perspectives of teaching and learning, as well as the conceptual change model (Appleton, 1997; Mortimer & Scott, 2003; Posner, Strike, Hewson, & Gertzog, 1982; Ryder & Leach, 2008). This initial framework, however, will be modified and enriched by the empirical data of this study to produce the final one to depict the key characteristics of NOS teaching.

Furthermore, this study seeks to explore the knowledge and skills that affect the practices of teachers and the effectiveness of NOS teaching. The instructional intentions and beliefs of teachers, as well as other external constraints, are set aside in this study.

The study aims to shed light on how to support science teachers in teaching NOS effectively, rather than how to *motivate* teachers to address NOS in their classrooms.

RESEARCH QUESTIONS

The central phenomenon explored in this study is how secondary science teachers in Hong Kong teach NOS in classrooms. The study is basically qualitative in its design; hence, the research questions are open and emergent. The general questions that guide the research directions and design are as follows:

1. How do a group of secondary science teachers in Hong Kong teach NOS in classrooms after attending a course on NOS teaching?
2. What is the discrepancy, if any, between the NOS conceptions of the teachers as assessed by the NOS instrument and as revealed by their NOS teaching?
3. What are the key characteristics of NOS teaching that are conducive to NOS learning?
4. To what extent do the teachers demonstrate these key characteristics in their NOS teaching?
5. What knowledge and skills do science teachers need to possess in order to demonstrate these key characteristics of NOS teaching?

SIGNIFICANCE OF THE STUDY

Past research on NOS teaching focused mainly on curriculum development, assessment of NOS understandings of teachers and students, and intentions of teachers in teaching about NOS, whereas direct examination of NOS teaching practices in actual classrooms has been largely missed. This study attempts to fill up part of the unexplored area in research: how do science teachers teach NOS in classrooms, and what are the knowledge and skills that teachers need to teach NOS? The study hopes to illuminate the research directions toward qualitative study of the complex processes of NOS teaching in actual classroom, rather than the quantitative, input-output design in previous NOS research. This line of research is likely to shed more important light on how to make NOS teaching actualized in classrooms.

The establishment of a framework for NOS teaching in this study has significance for both research and practice. Researchers can evaluate NOS teaching with the framework without needing to draw upon standardized NOS instruments, and a common framework also allows researchers to share and compare their data and findings. Science educators and science teachers also benefit from the framework by having clearer ideas about what effective NOS teaching would be like.

The previous efforts in promoting NOS teaching among teachers focus on the enhancement of the NOS understanding of teachers in out-of-classroom contexts, leaving the complex process of NOS teaching in actual classrooms untouched. With the findings from this study, science educators can target the skills and knowledge needed for effective NOS teaching and better equip teachers to teach NOS in their teacher professional development efforts. Only after science teachers are given sufficient support to address NOS aspects effectively and gain success experiences in NOS teaching would they begin to value the goal of NOS. Without resolving this deadlock, the disappointing outcomes of NOS teaching for half a century is likely to persist.

This study has local significance as well. Hong Kong started major curriculum reforms in 2000, in which all of the senior secondary science curricula have undergone major revisions. Nature of science has been given more emphasis in the curricula, particularly for biology and the new integrated science curricula (CDC & HKEAA, 2007a, 2007b). However, to many science teachers in Hong Kong, NOS is new and strange, let alone teach about it. From the perspective of a science educator in Hong Kong, fulfilling the obligation to promote NOS among science teachers and helping implement the new science curricula are imperative. Thus, local studies on NOS teaching in the classrooms of Hong Kong are indispensable. In the past, virtually no studies have been conducted on this aspect in Hong Kong.

RESEARCH METHODOLOGY

In view of the nature of the targeted phenomenon and the research questions, this study employs a *multiple case study* research design to study how eight secondary science teachers in Hong Kong teach NOS in actual classrooms. These teachers have participated in a NOS teaching course taught by the researcher as part of their pre-service/in-service education programs. The teachers have learned how to teach NOS effectively through the course, and they have been asked to teach NOS in their own classes. The teachers were chosen because they generally represent typical science teachers in Hong Kong. Although most of them are inexperienced biology majors, research generally finds that teaching experience and discipline have no effects on NOS teaching (Lederman, 2007).

The data collection and analysis of this study employ a *mixed-methods design* grounded on *pragmatism* (Tashakkori & Teddlie, 1998). Both quantitative and qualitative data were collected separately and concurrently from the eight cases, which were then merged for analysis. Hence, a *triangulation mixed methods design* (Creswell,

2008) was adopted, combining the strengths of both quantitative and qualitative data to interpret how teachers conduct NOS lessons. However, during data analysis, a greater *weight* was given to qualitative data over quantitative data

Quantitative data will be collected using two instruments: the Understanding of Science and Scientific Inquiry (SUSSI) (Liang et al., 2006) to assess the NOS understanding of participants and the Constructivist Teaching Questionnaire (Tenenbaum, Naidu, Jegede, & Austin, 2001), which was administered to the students of participants in order to evaluate the extent that the ordinary teaching of participants capture the features of constructivist pedagogy. The SUSSI is used because this study deliberately aims to explore the discrepancy, if any, between the NOS conceptions of participants, as measured by the NOS instrument and those revealed by the way participants discuss NOS in classrooms. Apart from these quantitative data, data pertaining to how participants teach NOS were largely qualitative in nature. The data included teaching videos and transcripts, interview audio records, teaching plans, teaching materials, self-reflections and the evaluations on the learning outcomes of students. The classroom talk of teachers and students in the teaching transcripts was converted into quantitative data to show the frequency of different kinds of talk, which, in conjunction with the teaching transcripts, were used to judge the communicative approach that teachers take in teaching NOS.

The main analysis focused on the NOS teaching of each participant. The teaching transcripts were read through, segmented and coded, and examined for evidence of effective/ineffective NOS teaching practices. A thick description of the NOS teaching of each participant was produced, wherein themes emerged inductively to account for the teaching practices of each participant. The whole process was iterative and cyclical, as proposed by Creswell (2008, p. 244). Subsequently, the themes identified from each case were triangulated among each other to look for common themes that can account for the teaching practices of all participants.

Chapter Two

Literature review

In this chapter, a wide range of literature pertaining to NOS teaching has been reviewed. The emphasis of review is placed on NOS teaching, while the issues pertaining to what NOS is, whether there exists a consensus of NOS aspects for pre-college science education, and how NOS conceptions are assessed are only briefly dealt with in the first section in order to provide a simple background for relevant discussions. The next section reviews approaches to teaching NOS, which consists of two subsections: explicit/implicit approach and contexts. A variety of contexts used for NOS teaching are examined, including historical case studies, socioscientific issues, inquiry lab activities and decontextualized NOS activities. The third section seeks to establish a preliminary theoretical framework for effective NOS teaching, which is needed to guide the design of the study and analysis of data. The framework is described in three subsections: approaches and contexts, constructivist pedagogy and conceptual change model, and classroom discourse and communicative approach. This framework is provisional and open, and is yet to be validated by the findings of this study. The last section explores the knowledge and skills of teachers that are needed for NOS teaching. They are discussed in four subsections: understanding about NOS, the PCK for NOS, general pedagogical orientations, and supports for NOS teaching.

ASPECTS OF NOS FOR PRE-COLLEGE SCIENCE EDUCATION

The Nature of Science generally refers to the issues as to what science is and how science works. More specifically, NOS encompasses what the epistemological and ontological underpinnings of science are, how scientists function as a social institution, and how science is related to society (Clough & Olson, 2008). The nature of science is a *hybrid domain* combining various *social studies of science*: history, sociology and philosophy of science, as well as cognitive sciences (McComas et al., 1998).

Over the past 30 years, there has been a heated debate among scientists and science educators, philosophers, sociologists, and historians over the nature of science. To date, the issues not only remain unresolved, but have become "both more contentious and more pressing than they were previously" (Matthews, 1998, p. 162). The complexity of the issues partly results from the diverse groups of stakeholders involved who look at the different aspects of the scientific enterprise. Science educators tend to be more concerned about NOS instruction and assessment, whereas philosophers of science are generally interested in the philosophical underpinnings and epistemology of science. Historians and sociologists of science, in contrast, prefer to examine the human interactions and social contexts in the course of scientific development. Scientists, in general, find most of these arguments irrelevant and nonsensical to their practice. Views not only vary considerably between groups but also within each group of stakeholders.

In the last decade, science educators have attempted to confine the discussions within the context of K-12 science education. They contend that the many of the unsettled issues are irrelevant and inaccessible to K-12 students, such as the arguments between realism and anti-realism, and the problems regarding "truth" in science. When the nature of science is described at higher levels of generality that are both appropriate and relevant to pre-college students, a consensus is present (Abd-El-Khalick et al., 1998; Lederman, 2007; McComas et al., 1998; McComas & Olson, 1998; Smith et al., 1997).

As a result, lists of *NOS tenets* for instruction and assessment have gradually emerged among science educators (Lederman, 2007; Lederman & O' Malley, 1990; Smith et al., 1997) and in science education reform documents, including the Benchmarks for Scientific Literacy (AAAS, 1993) and the National Science Education Standards (NRC, 1996). Below is a sample list of these NOS tenets:

1. Scientific knowledge, while durable, has a tentative character.
2. Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and skepticism.
3. There is no one way to do science (therefore, there is no universal step-by-step scientific method).
4. Science is an attempt to explain natural phenomena.
5. Laws and theories serve different roles in science. Therefore students should note that theories do not become laws even with additional evidence.
6. People from all cultures contribute to science.
7. Scientists require accurate record keeping, peer review and replicability.
8. Observations are theory-laden.
9. Scientists are creative.
10. The history of science reveals both an evolutionary and revolutionary character.
11. Science is a part of social and cultural traditions.
12. Science and technology impact each other.
13. Scientific ideas are affected by their social and historical milieu.

(McComas et al., 1998, p. 513)

Others, mostly science philosophers, are quick to disagree with the NOS tenets proposed by science educators, arguing that no consensus really exists and these tenets have wrongly portrayed a unitary, oversimplified nature of science (e.g., Alters, 1997a, 1997b; Duschl, 2006; Kuhn, 1996; Matthews, 1994). The most widely cited empirical work for the disagreements comes from Alters (1997a), who surveyed approximately 200 science philosophers in the US and found that their views on the NOS tenets vary considerably, with some expressing major criticisms against the tenets. As high as 40% of the science philosophers surveyed disagreed with the most important NOS tenet: "Scientific knowledge is tentative and should never be equated with truth" (Alters, 1997a, pp. 48-49). The methodology and conclusions of the study of Alters, however, have been seriously criticized (Eflin, Glennan, & Reisch, 1999; Smith et al., 1997).

Apart from the debates between science philosophers and science educators, the simplified NOS tenets also do not get support from scientists as well. Surprisingly, when evaluated by these NOS tenets, scientists do not necessarily hold "informed" conceptions of NOS (Glasson & Bentley, 2000; Kimball, 1967-68; Pomeroy, 1993). In a study by Schwartz and Lederman (2006), 24 practicing scientists were surveyed regarding their views about the nature of science and scientific inquiry. The findings reveal that scientists vary considerably in their views on certain agreed upon NOS tenets (pp. 29-33). For example, only 45.8% of these scientists affirmed that scientific knowledge is inherently tentative, while 20.8% held that scientific knowledge is absolute and certain, and another 16.7% thought that science is approaching certain knowledge (p. 29). Strikingly, a significant proportion of scientists hold naive *absolutist* views of science. When asked regarding how to justify a claim, 58% of the scientists expressed that it varies enormously from field to field and by context (p. 19). These diverse, "contextually based epistemological views of science" (p. 22) shown by the scientists lend support to the view that the nature of science cannot and should not be represented by simplified NOS tenets. These general NOS tenets presuppose "an essentialist view of science" (Eflin et al., 1999, p. 108) wherein all science activities/disciplines can be defined by a set of essential characteristics. This view, however, has been abandoned by many science philosophers (Eflin et al., 1999). Philosophers may hold a realist view towards some scientific theories, but hold an anti-realist view on others. Most of the generalized NOS statements are "contextual with important exceptions" (Clough, 2005). A case in point is the statement "Science is tentative" which might be appropriate for the theories explaining why dinosaurs became extinct, but is at odds with the observation that Earth is nearly round (Elby & Hammer, 2001). Some argue that many of these "general" aspects of NOS have come from the study of the physical sciences, while biological sciences are of a quite different nature (Mayr, 1998; Rosenberg, 1994).

While these general NOS tenets/statements may be useful for planning NOS teaching and assessment, they are easily misunderstood by teachers as the mere outcomes of NOS learning that students need to display (Clough, 2005). Thus, teachers may have the students learn the NOS tenets by rote without attending to the "contextual nuances" and the richness of NOS aspects (Elby & Hammer, 2001, p. 555).

Another problem with the general NOS statements is their fragmentary nature. Many aspects of NOS are interrelated and cannot be resolved into separate statements (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Schwartz & Lederman, 2006). A particular aspect of NOS only makes sense in specific contexts, and may be contradictory with other aspects of NOS when viewed generally. Good and Shymansky (2001) find that most of the NOS statements in the National Science Education Standards (NRC, 1996) and the Benchmarks for Science Literacy (AAAS, 1993) describe science in contrasting ways:

1a. Scientific ideas are tentative and open to change.

1b. Most scientific ideas are not likely to change greatly in the future.

2a. It is normal for scientists to differ with one another about ideas and evidence.

2b. Scientists work toward finding evidence that resolves disagreements.

3a. Scientists are influenced by societal, cultural, and personal beliefs, and ways of viewing the world.

3b. Explanations on how the natural world changes based on myths, personal beliefs, religious values, or authority are not scientific.

4a. All scientific knowledge is subject to change.

4b. The core ideas of science are unlikely to change.

(Good & Shymansky, 2001, p. 171, p. 201)

When presented with these contrasting statements without being grounded in specific contexts, students are likely to be confused or may shift from one extreme to another; this is because students tend to see things in black or white (Clough, 2005). To learn that science is both tentative and durable, students should be taught when and why science is tentative for a specific case, and when and why science is largely durable in general. Students have to acquire the ability to judge the tentativeness or durability of a specific scientific claim, rather than remembering these general NOS statements by rote. To avoid the misuse of the NOS tenets, Clough (2005) proposes converting the NOS tenets into *NOS questions*, such as "In what sense is scientific knowledge tentative? In what sense is it durable?" (Clough, 2005, p. 3–4)

In summary, the use of the "consensus" NOS tenets to guide NOS instruction remains debatable; however, most science educators agree that these tenets outline the scope of the NOS aspects appropriate for K-12 science teaching. These tenets need not to be abandoned; they simply have to be reconceptualized as general guidelines for NOS teaching, rather than being portrayed as truths that can be applied without exceptions in all contexts of science, and as mere learning outcomes that students should acquire. The dialectical nature of these tenets has to be addressed through contextually based teaching in a spirit of inquiry rather than indoctrination.

APPROACHES TO TEACHING NOS

NOS instruction can be approached in a variety of ways. This section explores the two most important and well researched dimensions of the approaches to teach NOS: the *explicit/implicit* approach, and the contexts of teaching NOS.

Implicit and explicit approach

Lederman (2006) has identified three general approaches to NOS teaching: *implicit, historical*, and *explicit* (p. 311–312). The implicit approach engages students in hands-on, laboratory-based inquiry activities without explicitly pointing out or allowing students to reflect on aspects of NOS during the process (e.g., Haukoos & Penick, 1985; Riley, 1979; Spears & Zollman, 1977; Trent, 1965; Troxel, 1968). This approach assumes that students develop NOS understanding as a by-product of "doing science" (Lawson, 1982), and that NOS learning outcomes are largely *affective* rather than *cognitive* (Barufaldi, Bethel, & Lamb, 1977; Riley, 1979). The historical approach incorporates history of science in science teaching (e.g., Abd-El-Khalick & Lederman, 2000a; Klopfer & Cooley, 1963; Solomon, Duveen, Scot, & McCarthy, 1992; Welch & Walberg, 1972; Yager & Wick, 1966). The explicit approach emphasizes explicit planning and teaching for NOS aspects, instead of viewing NOS learning as a by-product of science teaching. In this approach, the attention of students is deliberately drawn to important NOS aspects "through discussion, guided reflection, and specific questioning in the context of classroom science activities" (Schwartz & Lederman, 2002, p. 207). The explicit approach varies widely in its contexts, including historical cases of science, scientific inquiry activities, decontextualized NOS activities, and a composite of these.

The above categorization, however, is not without problems. The historical approach overlaps with the other two approaches: an instruction utilizing history of science could be explicit and implicit with regard to the NOS aspects. In an extensive review of the literature on NOS teaching, Abd-El-Khalick and Lederman (2000a), however, propose only two approaches: *explicit* and *implicit.* They clearly distinguish the "kinds" of activities from "the extent to which learners are provided . . . some key aspects of NOS" (p. 690). In this study, the "kinds" of activities are referred to as *contexts* of NOS teaching, which includes historical cases of science and other activities. This system of *explicit/implicit* approach and *context* is less confusing and more encompassing than the *explicit/implicit/historical* system that Lederman (2006) proposes.

There is extensive evidence that the explicit approach could generally produce desirable changes regarding the NOS conceptions of students, whereas the implicit approach is largely ineffective (Abd-El-Khalick & Lederman, 2000a, p. 692; Lederman, 2007, p. 869). This conclusion, however, has to be taken with some caution. First, classifying a study into these two categories is not clear-cut at all. For instance, Bell, Lederman, and Abd-El-Khalick (1998) have queried Palmquist and Finley's (1997) "implicit" NOS teaching because they found "substantial direct instruction" in the study. The "implicit" approach (Craven, Hand, & Prain, 2002; Scharmann, 1990; Scharmann and Harris, 1992), as claimed by their authors, often involves class discussions in which the guidance of teachers is inevitable. This makes their claimed "implicit" approach doubtful. Second, the validity of the assessment instruments used in these studies has been called into doubt, particularly the quantitative instruments such as TOUS, WISP and SPI (Lederman, 2007; Lederman et al., 1998). This poses threats to the validity of the gains of the interventions reported, whether implicit or explicit. Third, attributing the success of an intervention to its explicitness, regardless of the context it utilizes to convey the NOS aspects, would be problematic. Studies that are deliberately designed to examine the interactions of the explicit/implicit approach with different contexts are rare.

Contexts

Apart from the explicitness of attending to NOS aspects during instruction, the attempts to enhancing the NOS understanding of teacher and students have utilized a variety of *contexts* to convey the NOS conceptions, including direct instruction (e.g., Abd-El-Khalick, 2005; Craven et al., 2002); history of science (e.g., Klopfer & Cooley, 1963; Lin & Chen, 2002); hands-on school scientific investigations (e.g., Abell, Martini, & George, 2001; Shapiro, 1996); authentic scientific inquiry (e.g., Bell et al., 2003; Schwartz et al., 2004); contemporary socioscientific issues (SSI) (e.g., Craven et al., 2002; Scharmann, 1990); and decontextualized, content-free NOS activities (e.g., Lederman & Abd-El-Khalick, 1998) as well as a composite of these contexts (Abd-El-Khalick, 2001, 2005). In light of the diversity of contexts employed, categorizing NOS instruction as explicit or implicit irrespective of its context would be inadequate. The effectiveness of an NOS instruction would depend on a complex interplay between contexts and its degree of explicitness. These contexts for NOS teaching will be examined respectively in the following sections.

Direct instruction

Some studies, specifically those on science teachers, directly address NOS aspects through lecture and/or reading of articles (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Craven et al., 2002). Direct instruction does not necessarily mean that NOS aspects are taught without contexts at all. The instruction is organized by the NOS aspects or NOS tenets, while simple examples from historical and contemporary cases of science are drawn upon for illustration. In the explicit/implicit continuum, this form of instruction is at the most explicit end. However, this kind of direct NOS instruction, like a philosophy of science course, is probably inappropriate for precollege students due to its abstractness and decontextualized nature.

History of science

The incorporation of the history of science into science curricula has been advocated by educators and historians of science for over 60 years (DeBoer, 1991). In the beginning, the history of science was not promoted specifically for enhancing the understanding of NOS, but rather for providing a humanistic and authentic context for science content learning (e.g., Clough 1997; Matthews, 1994; Solomon et al., 1992). Some early prominent efforts include the *Harvard Case Histories in Experimental Science* (Conant & Nash, 1957), the *History of Science Cases* (Klopfer & Cooley, 1963) and the *Harvard Project Physics* (Rutherford, Holton & Watson, 1970). Recent science curriculum reform efforts in the 90s also place the history of science at the center of science education. In *Beyond 2000: Science Education for the Future*, Millar and Osborne (1998) contend, "scientific knowledge can best be presented in the curriculum as a number of key explanatory stories" (p. 14).

Despite the emphasis of the curriculum documents and the efforts by science educators, surprisingly, the history of science had made little impact on science teaching in K-12 classroom (Duschl, 1994; McComas, 2008). The prevalent use of science history, as shown in the popular science textbooks, is the haphazard insertion of short vignettes regarding prominent scientists, with the aims of humanizing and adding an element of entertainment to content-based science teaching (Stinner, Mcmillan, Metz, Jilek, & Klassen, 2003). These historical vignettes are often oversimplified, inaccurate and even erroneous, and the scientists and their processes of scientific discovery are usually dramatized and romanticized. The inclusion of this kind of science history is not aimed at learning concepts, science process or nature of science; rather, these stories are mainly for motivational purposes. This makes the history of science largely unable to produce the benefits it advocates.

One main reason for the unsatisfactory incorporation of the history of science into science teaching is that science teachers largely find teaching history of science in conflict with the primary goal of science teaching: the delivery of science concepts (Olson, Clough, Bruxvoort, & Vanderlinden, 2005; Stinner et al., 2003). Science teachers consider teaching history of science the work of history teachers (Heilbron, 2002) and are reluctant to sacrifice the class time in teaching about subject matter. In light of this, to be adopted by science teachers, the historical stories have to be closely tied to the science concepts of the curriculum, an "integrated approach" suggested by Matthews (1994). For example, the biology teachers of Hong Kong are less likely to resist teaching the histories associated with the theory of evolution, the discovery of DNA structure and the fluid mosaic model of cell membrane because they are all closely associated with the contents of the curriculum (CDC & HKEAA, 2007a).

Another issue pertaining to teaching through history of science is how accurate and authentic the history should be. To be used for science teaching, the history has to be selected, simplified and reconstructed in ways that not only fit into the content-based science curriculum, but are also pedagogically sound for the secondary students. This inevitably leads to the following tension:

> a tension naturally exists between accurately reporting all details in the historical development of ideas and efforts to accurately convey the nature of science and scientists without transforming science courses into history of science courses.
> (Metz, Klassen, McMillan, Clough, & Olson, 2007)

Some historians of science insist that no history is better than *distorted* history (Allchin, 2003; Klein, 1972; Matthews, 1994; Whitaker, 1979). This distorted history could be *pseudo-history*, where something is missed or incorrect, or *quasi-history* in which the history has been "rationally reconstructed" (Lakatos, 1971) for the convenience of teaching and learning (Whitaker, 1979). Brush (1974) calls this the *whig view of history* in which science is portrayed as a cumulative, inexorable progression toward the modern understanding, as viewed from the present perspectives, largely neglecting the social and historical contexts of the time. Matthews (1994, p. 80), however, defends this reconstruction as inevitable for pedagogical needs, and that applying high standards of historical research to science teaching would be unfair. After all, given Kuhn's (1996) principle of incommensurability, students or even science teachers would find the evolving historical ideas at odds and incomprehensible if they are not *rationalized* and *reconstructed* to some extent (Solomon et al., 1992).

Another problem with teaching NOS through history of science is that different people may associate the same historical event with quite contradictory aspects of NOS.

For instance, the discovery of the benzene structure by August Kekule was taken as an example of the evidence-based nature of scientific model by Okasha (2002) and Derry (1999). To the contrary, this discovery was linked to the role of creativity in science by Wolpert (1994). It thus raises the question as to what aspects of NOS a particular history is really revealing, which is even debatable among the experts, not to say among science teachers and students.

History of science can be incorporated into teaching in a variety of ways. The length of the story can be the shortest *vignette* or *anecdote* (e.g., Wandersee, 1992) commonly found in science textbooks, a short story (e.g., Clough, 1997; Solomon et al., 1992; Tao, 2003), or the longest, most elaborate *storyline*, *theme* or *case study* that consists of a series of episodes over an extended period of time around one unified central idea, such as “Is matter made of atoms?” (Metz et al., 2007; Stinner et al., 2003). Matthews (1994) calls these treatments of the history of science the *minimalist* and *maximalist* approaches. In addition, history can be presented in different forms: debate (e.g., Copernicus and the Aristotelians), dialogue (e.g., Priestley and Lavoisier), drama (e.g., the trial of Galileo), reproduction of historical experiments, reading of original papers, and projects (Matthews, 1994; Stinner et al., 2003). However, these ways of presenting history are heavily critiqued by Allchin (1995) as *rational reconstructions* of the history from the current perspective, largely distorting the perplexing nature of scientific progress in the historical context.

Metz et al. (2007) conceptualize teaching through the history of science as creating a historical narrative, such that a teacher has to attend to certain *narrative elements*: *appetite, purpose, agency,* and *structure*. Of particular importance is narrative appetite, which is “the desire created in readers and listeners to know what will happen.” They argue that only with enough narrative elements can a story be ‘real’ and ‘convincing’ to students.

Research shows that students will selectively attend to the information in story that conforms to their existing ideas, while unconsciously neglecting or modifying the parts that contradict their beliefs (Abd-El-Khalick & Lederman 2000b; Tao, 2003). Hence, given the naïve NOS conceptions commonly held by students, simply presenting them with science stories would have minimal effect in changing their NOS conceptions (Clough, 2006). One effective strategy is the *interrupted story approach* (Roach & Wandersee, 1995), in which the story is broken down into smaller sections in order that mediations can be done after each section. Capitalizing on the conceptual change model of teaching (Driver & Oldham, 1985), Metz et al. (2007) have proposed some strategies for effectively using historical narratives in science teaching as follows:

1. Activate prior knowledge through activities that capture student interest and connect students’ background with the story details. This can be done within or independently of the story.
2. Use an interrupted story approach to enable students to make inferences and predictions
3. Solicit individual and/or group reactions while asking open-ended questions.
4. Employ compare and contrast strategies that relate student ideas to the historical ones.
5. Provide for related demonstrations and experiments, projects and research, and cross-curricular integration.
6. Use writing activities such as a log or journal, for reflections and question generation.
7. Use guided reading strategies such as issue-based analysis or paired reading

(pp. 320–321)

Monk & Osborne (1997) have proposed a *constructivist pedagogic model* for science teaching using history of science and experiments (Figure 2.1). In the model, the ideas of students on a historical phenomenon are first elicited. The ideas are then tested with experiments in order to introduce the formal scientific explanations. Although this model is not specifically proposed for NOS teaching, but it gives a clear steps of instruction that may illuminate NOS teaching as well.

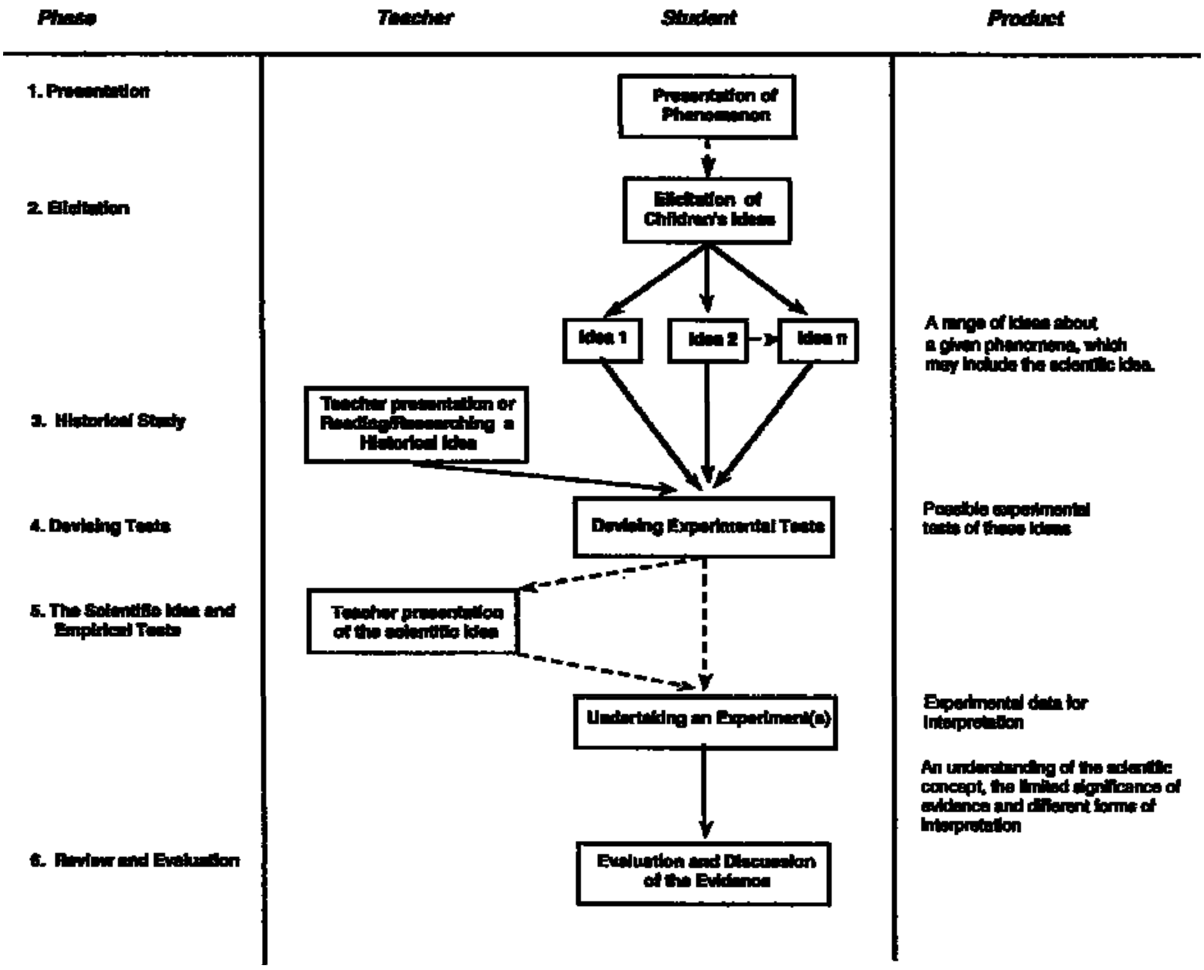

Figure 2.1 Model of teaching using history of science (Monk & Osborne, 1997, p. 415)

Apart from the pedagogy, another main obstacle to teaching about NOS through the history of science comes from the lack of suitable teaching resources. Expecting science teachers to develop accurate and appropriate historical cases for NOS teaching on their own would be unrealistic because most of them lack good understanding of both the nature of science and the history of science (Brickhouse, 1990; Koulaidis & Ogborn, 1995). Although there is no shortage of popular science story books, such as *Science: 100 Scientists Who Changed the World* (Balchin, 2003), these books focus largely on the biographies of famous scientists to the exclusion of the historical development of science concepts, not to mention the nature of science embedded in the stories. Written by scientists, books such as *The Double Helix* (Watson, 2001), *DNA* (Watson & Berry, 2004), and *The Discoveries* (Lightman, 2005), provide accurate and elaborate accounts of the historical development of important scientific ideas; however, transforming them into teachable materials requires tremendous efforts. Books by science philosophers, historians of science, as well as scientists, such as *What is this Thing Called Science?* (Chalmers, 1999) and *Unnatural Nature of Science* (Wolpert, 1994), are written primarily to introduce the philosophy and/or nature of science to the public, but not for teaching purposes. Unfortunately, resources having accurate but concise historical cases that are not only connected with important aspects of NOS, but also readily usable by teachers with minimum adaptation, are uncommon. One of the few exceptions are the book *Exploring the Nature of Science* (Solomon, 1991), and some online resources (Science for Public Understanding, 2004; University of Berkeley, 2004; University of York/Nuffield Foundation 2004), but they are yet to be adapted to the local science curricula of teachers in different countries/regions. Without an adequate supply of appropriate teaching resources, teaching NOS in the contexts of history of science would be severely limited.

Is teaching NOS in the context of science history effective? Despite the conclusion of Lederman (2006) that it is “at best, inconclusive” (p. 311), research findings seem to indicate otherwise. Many studies using the history of science have obtained positive gains on the NOS understanding of students (e.g., Klopfer & Cooley, 1963; Lavach, 1969; Lin & Chen, 2002; Solomon et al., 1992; Tao, 2003; Yager & Wick, 1966), although a few others have produced inconclusive results. Hence, the historical approach to NOS instruction could be said effective in general.

Socioscientific issues (SSIs)

SSIs are social issues that are connected to science (Sadler, Chambers, & Zeidler, 2004). In the techno-scientific world in which we live, the news media are full of this type of issue, such as the controversy about the causes of climate change, the ethical dilemma of stem cell research, the potential harmful effects of the cellular phones, and so on. These issues provide a rich and interesting context for teaching NOS, particularly on the credibility, tentativeness, limitations and socio-cultural embeddedness of science and technology. Research finds that the responses of students to SSIs are related to many important aspects of the NOS (Sadler, et al., 2004; Shibley, 2003; Zeidler, Walker, Ackett, & Simmons, 2002).

Though there is no shortage of SSI in the media reports, at hand and timely issues related to the science curricula and readily used by teachers are uncommon. The teacher has to transform the SSIs into effective NOS teaching, which means identifying the NOS aspects from the issues, making the issues and the associated science contents accessible to students, and designing effective activities and lesson plans to engage the students. These all pose serious barriers to teaching NOS through SSIs. Compared to historical case studies, teaching SSI involves more contemporary and frontier knowledge of science and technology, which are often beyond the scope and depth required by the science curricula, and even beyond the understanding of science teachers. A case in point is Clough's (2006) use of the issue appearing in the news: why the Pioneer 10 and 11 space probes are slowing down when they are far away from the solar system, which involves the knowledge of *dark matter*.

However, SSIs are more effective than historical case studies in teaching some aspects of NOS. First, these issues actually occur in the daily lives of students, representing truly “authentic” science rather than those in the history. Secondly, these issues remain largely unresolved until now, such that students are compelled to reflect on the limitations and perplexing nature of science. Most of the historical cases, on the contrary, have been satisfactorily resolved with a single “right” answer, thus portraying a naïve understanding that science progresses inexorably towards a true understanding of nature as it is. Finally, SSIs do not have the problem of appraising the historical events from current perspectives.

Inquiry lab activities

It had been an intuition that understanding of NOS is best achieved through ‘doing’ science. Many science education reform efforts have emphasized the role of inquiry in developing students’ understanding of NOS (AAAS, 1993; NRC, 1996). However, research generally does not lend support to this notion; engaging students in hands-on, laboratory inquiry activities without explicit attention to NOS aspects is ineffective in enhancing their NOS views (Abd-El-Khalick & Lederman 2000a; Durkee, 1974; Haukoos & Penick, 1985; Khishfe & Abd-El-Khalick, 2002; Moss, 2001; Riley, 1979; Spears & Zollman, 1977; Trent, 1965; Troxel, 1968). This is referred to as the *implicit inquiry-based pedagogical approach* (Schwartz et al., 2004). However, when teachers deliberately draw students’ attention to aspects of NOS during inquiry process, which is called the *explicit inquiry-based pedagogical approach,* inquiry activities can create positive changes in students' NOS conceptions (Abell et al., 2001; Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002; Shapiro, 1996). Therefore, it is oversimplified to claim that inquiry lab activities are effective or not in NOS teaching irrespective of the explicit/implicit approach they take.

Given the huge difference between school inquiry activities and *authentic scientific inquiries* practiced by real scientists (Chinn & Malhotra, 2002), some attribute the ineffectiveness of the *implicit inquiry-based pedagogical approach* to the lack of authenticity. However, research shows that even when engaged in authentic science in the apprenticeship programs with real scientists, the NOS views of the participants does not improve significantly if the NOS aspects are kept implicit (Bell et al., 2003; Schwartz et al., 2004). A study by Ryder, Leach and Driver (1999) found that undergraduate science students improved only in one NOS aspect over a 5-8 month period of project work: the lines of scientific enquiry are influenced by theoretical developments within a discipline. In addition, scientists, who have practiced authentic science for an extended period of time, have likewise been found not to hold "adequate" views of NOS (Bell, 2000; Glasson & Bentley, 2000). Schwartz et al. (2004) explained this finding as scientists' lack of reflection from the outside, a *cognitive disengagement* from the scientific activities, such that they can take a reflective stance on their own experiences. This paradox is also probably a result of the issue of what counts as "adequate" views of NOS as discussed earlier.

Scientific investigations at school, however, vary considerably in their *authenticity*. McComas (1997) characterizes the openness of lab activities in four levels (Table 2.1). Only lab activities at Level 2 or above could be counted as *investigations*, in which students design and conduct tests for a hypothesis, and draw their own conclusions, while Levels 0 and 1 are just laboratory *experiences* and *exercises* aimed at ‘feeling’ the phenomena and mastering procedure skills (Woolnough & Allsop, 1985). The higher the level of the practical work, the more it captures the features of authentic scientific inquiry, and the more likely various aspects of NOS would emerge in the process.

Table 2.1 Schwab/Herron Levels of Laboratory Openness (McComas, W. F., 1997)

Levels	Problem	Ways & Means	Answers
0	given	given	given
1	given	given	open
2	given	open	open
3	open	open	open

Lederman and Lederman (2004) have demonstrated how “almost any science activity can be modified to explicitly teach some NOS aspects, without much effort, loss of class time , or loss of attention to important subject matter.” They use the study of mitosis in plant root tips as an example, a popular lab activity in which students are asked to count the cells at different stages of mitosis, and then calculate the relative time each stage of mitosis lasts. Lederman and Lederman encourage the students to think about why different students come up with different numbers of the stages of mitosis even though they are examining the same specimen, showing the students that the classification of the stages of mitosis is arbitrary and subjective to some extent. Similarly, Colburn (2004) challenges students to identify different samples of unknown white powder in order to show the role of theory-ladenness when students choose tests for each powder and interpret the results. The examples provided by Lederman and Lederman (2004) and Colburn (2004) have shown that even highly simplified school investigations, when sufficiently open and coupled with reflective discussions on the aspects of NOS, could result in fruitful outcomes regarding NOS understandings.

However, science practical work in Hong Kong is dominated by *lab experiences* and low-level *cookbook* experiments, which merely require students to experience the phenomena and follow prescribed steps in doing experiments (Yip & Cheung, 2004; Martin, Mullis, Gonzalez, & Chrostowski, 2004; Tsang, 2004), and likely in many other countries as well. As such, teaching NOS through inquiry lab activities would require intensive changes in the practices of a teacher. Lederman (2006) describes it as *developing an instructional syntax within the inquiry-oriented environment* (p. 313). This added challenge makes inquiry lab activities less suitable for teachers who are not used to open-ended scientific inquiry.

Decontextualized NOS activities

There is a distinct group of NOS instructional activities that are free of science content and decontextualized from the real science enterprises (Bell, 2008; Clough, 1997; Lederman & Abd-El-Khalick, 1998; Warren, 2001). They are puzzle-solving or black box activities simulating scientific inquiry. For example, in the Tricky Tracks (Lederman & Abd-El-Khalick, 1998, p. 85–91), students are presented with some mysterious tracks of birds and are required to account for what has happened. In the Water Making Machine (Lederman & Abd-El-Khalick, 1998, p. 117), students are challenged to explain why the Machine can flow out more water than what has been put in. Pictorial gestalt switches are used to illustrate the theory-ladenness and subjectivity of observations, such as the Morphing Man (Bell, 2008) and the Young and Old Woman (Lederman & Abd-El-Khalick, 1998). Lederman and Abd-El-Khalick (1998) have collected, adapted and devised some highly popular decontextualized NOS activities, providing useful materials for NOS instruction. Later, Bell (2008) and Warren (2001) likewise also published books providing many useful decontextualized NOS activities with detailed lesson plans, teacher notes, and student worksheets.

Lederman (2006) describes these decontextualized NOS activities as "classroom-tested activities for the successful teaching of NOS… used in my research group's work with teachers and their students over the past 15 years" (p. 313). Lederman and Abd-El-Khalick (1998) have proposed the following *generalized pedagogical model* for the Black Box activities based on the conceptual change model.

1 demonstration of a discrepant phenomenon
2 open-ended inquiry
3 making observations and inferences
4 proposing hypothesis and prediction
5 testing the hypothesis
6 discussion on the NOS aspects explicitly.

These decontextualized NOS activities can be used to address quite different aspects of NOS and in varying effectiveness. For example, the Mystery Tube is used by Lederman and Abd-El-Khalick (1998, p. 114) to address the nature of scientific model, but Bell (2008, p. 127–129) could use it further to show students the differences between scientific laws and theories. In the Tricky Tracks (Lederman & Abd-El-Khalick, 1998, p. 85–91), students are asked to account for the mysterious tracks on the beach so as to show them the differences between observation and inference, and the role of creativity in science. The authors emphasize that all inferences are equally plausible so long as they are consistent with the evidence, which portrays a more *relativist, constructivist* view of science. In a very similar activity adapted by Bell (2008, p. 73–78) and now called Fossil Tracks, students are required to scrutinize the *plausibility* and *empirical adequacy* of their “theories” to find out the “best” one. As such, students are led to understand a more accurate aspect of NOS than that in the Tricky Tracks. Hence, the activities themselves cannot guarantee the success of NOS instruction, which depends heavily on how teachers utilize the activities.

One major deficit of this kind of decontextualized NOS activities is that they are not science but merely *simulations* of science. When comparing the Fossil Tracks of Bell (2008) with the Birds’ Tracks of Lederman and Abd-El-Khalick (1998), we can easily notice that the Fossil Tracks represents more *authentic science* because it involves real fossil tracks of dinosaurs and explanations of paleontologists. Clough (2006) has developed a framework to characterize various NOS instructions on a *decontextualized/contextualized* continuum (Table 2.2). At the one end are the *decontextualized NOS instructions* such as the black box activities, while at the other end are the *highly contextualized NOS instructions* using science history and SSIs. The decontextualized activities are advantageous in that they allow students to easily grasp the NOS conceptions in a familiar, concrete, and interesting context without being complicated by the science content. However, as *simulations* for real science, this type of activities is likely to produce conceptual changes merely within the context of the activities, leaving the original NOS conceptions of students regarding *authentic science* unchanged or parallel with the newly acquired conceptions. Nevertheless, the decontextualized activities are still useful as scaffolding for the highly contextualized activities (Clough, 2006).

In summary, despite the abundance of materials providing decontextualized NOS activities, the successful utilization of these materials requires teachers to enact them sophistically in the classroom. These activities should be connected with some science content in order to make them more similar to authentic science. A good planning for NOS teaching should move back and forth along the continuum, utilizing the decontextualized activities as scaffolds for the more contextualized activities. This approach has gained initial support from empirical study (Clough and Olson, 2001).

Table 2.2 Important features in the decontextualized to highly contextualized explicit nature of science continuum (Clough, 2006, pp. 476–477)

	Explicit decontextualized NOS	→		**Explicit highly contextualized NOS**
Connection to science content	none	Embedded in, but still distinct, from science content		Seamless
Connection to authentic science	How is this activity/reading like science or what scientists do?			How is this authentic incident/NOS issue illustrated in prior NOS and lab activities?
Exemplar activities	Black box activities, Gestalt switches, puzzle solving	Decontextualized activities linked to science content	Inquiry science content activities linked to NOS	Drawing students' attention to NOS issues in authentic historical and contemporary science incidents, and using the words of scientists accurately conveying what science is like
'Outs' students have to exit without deep conceptual change	These activities are not science	The science content is much different than the NOS activities	Scientists are smarter and have better equipment, more experience, more resources, and larger teams.	The historical and contemporary science incident is incomplete or not accurate. The particular scientist's perspective is not representative of all science or scientists. Students misinterpreting the historical or contemporary incident.

FRAMEWORK FOR NOS TEACHING

What constitutes good NOS instruction is at the heart of research and practice regarding NOS teaching. A comprehensive framework for NOS teaching, however, is absent in the extant literature. Many studies focus on a particular aspect of NOS teaching without attending to other variables, for example, on the explicit/implicit approach but neglecting the context. Some simply judge "successful" NOS teaching by "the identification of attempts to plan for and teach NOS explicitly" (Schwartz & Lederman, 2002, p. 229), leaving the features of successful NOS teaching completely untouched. Only a small number of empirical studies have examined classroom NOS teaching in depth and seek to identify key features of effective NOS teaching (e.g., Abd-El-Khalick & Akerson, 2004; Bartholomew et al., 2004; Beeth & Hewson, 1999; Smith, Maclin, Houghton, & Hennessey, 2002). This section seeks to synthesize these empirical findings and draw on models of effective teaching, in general and effective NOS teaching, in particular (e.g., Clough, 2005, 2006) to construct a comprehensive framework for the characterization of effective NOS instruction. With this framework, the NOS teaching of the participants can be analyzed and evaluated. In return, the findings of this study also help validate and refine the framework, and the final framework is presented in the chapter of Conclusion. In this section, the framework is discussed in three dimensions: approaches and contexts, constructivist pedagogy, and communicative approach.

Approaches and contexts

Extensive evidence supports that *explicit* approach to NOS teaching could produce desirable changes regarding the NOS conceptions of students and teachers, whereas *implicit* approach is largely ineffective (Abd-El-Khalick & Lederman, 2000a; Lederman, 2007). This conclusion, however, is made regardless of the contexts used. With regard to the contexts, Abd-El-Khalick and Lederman (2000a, p. 694), arrive at a conclusion that:

> approaches that utilize elements from history and philosophy of science and/or direct instruction on NOS are more effective in achieving that end than approaches that utilize science process-skills instruction or non-reflective inquiry-based activities.

This conclusion, however, has to be understood in connection with the explicit/implicit approach. Teaching NOS through the history of science can be ineffective when it does not intentionally target NOS aspects (Abd-El-Khalick & Lederman, 2000a). Only when the history of science is deliberately used to convey NOS conceptions might desirable outcomes be effected (e.g., Lavach, 1996; Lin & Chen, 2002; Tao, 2003; Solomon et al., 1992; Yager & Wick, 1966). Similarly, inquiry-based activities found ineffective in facilitating NOS understanding are often a result of their *implicit* nature (Abd-El-Khalick & Lederman 2000a; Durkee, 1974; Haukoos & Penick, 1985; Khishfe & Abd-El-Khalick, 2002, Moss, 2001; Riley, 1979; Spears & Zollman, 1977; Trent, 1965; Troxel, 1968). When the NOS aspects are deliberately addressed in the inquiry process, positive changes in the NOS conceptions of students can be effected (Abell et al., 2001; Akerson et al., 2000; Khishfe & Abd-El-Khalick, 2002; Shapiro, 1996).

Direct instruction of NOS aspects through lecturing and reading, despite its effectiveness for pre-service and in-service teachers in the undergraduate and postgraduate courses (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Craven et al., 2002), is dubious for its effectiveness and appropriateness for precollege students. When NOS aspects are directly addressed in general statements rather than in specific contexts, they are hardly intelligible and interesting to young students. Moreover, science teachers are likely to resist direct NOS instruction as it does not connect with science content at all.

Although the various contexts for explicit NOS teaching are effective in general (Abd-El-Khalick & Lederman, 2000a), they have their respective limitations and strengths as discussed in the previous sections. Effective NOS teaching through these contexts has to attend to these issues. One important issue is the extent that the context represents authentic science. Decontextualized NOS activities are considered effective in teaching NOS by some NOS researchers because they are explicit, motivating and content-free (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Akerson et al., 2000). However, from the perspectives of Clough (2006) (see Table 2.2), students are most likely to exit the instruction by these activities without conceptual change because they tend to dismiss these activities as authentic science. The contexts representing authentic science, SSIs and history of science, are more likely to produce changes of the NOS conceptions of students, but they fall short of being heavily loaded with science content and complicated by the social and historical contexts. Hence, effective NOS teaching through history of science and SSIs not only requires accurate depictions of the history and the issues, but also a pedagogical transformation of them into forms that are accessible and interesting to students. Scientific investigations as contexts to teach NOS may turn out to be recipe-type experiments that only provide *experiences* and *exercises* (Woolnough & Allsop, 1985). Science teachers need to skillfully modify lab activities into more open inquiries and draw students' attention to the tacit NOS aspects in the inquiry process as Lederman and Lederman (2004) demonstrated.

In summary, most of contexts utilized for NOS instruction reviewed thus far, when used in an explicit manner, are empirically supported to be effective, except SSIs and direct instruction for precollege students. The use of these contexts, however, does not guarantee effective NOS teaching without attending to their respective limitations. A curriculum with an emphasis on NOS, therefore, is better to incorporate a mix of these contexts.

Constructivist pedagogy and conceptual change model

Given the widely known naïve NOS conceptions held by students, effective teaching of NOS is best informed by constructivist perspectives and the conceptual change model of teaching and learning (Appleton, 1997; Posner et al., 1982). From the conceptual change perspectives, whether a new concept can replace the old one depends on the relative *status* of the new and old concepts in the eyes of the learners (Hewson & Thorley, 1989). The status of a concept, in terms of its *intelligibility*, *plausibility*, *fruitfulness*, and *dissatisfaction*, would be judged against the *conceptual ecology* of the learners, which comprises their other knowledge, anomalies and epistemological and metaphysical beliefs of the learners (Alsop & Watts, 1997; Posner et al., 1982). According to the conceptual change model, a teacher has to first lower the status of the naïve NOS conceptions of students, such as creating a *cognitive conflict*, and then raise the status of the targeted NOS conceptions by making them intelligible, plausible and fruitful in the contexts of instruction (Hewson, Beeth, & Thorley, 1998). The conceptual change model has been extended to include the *affective*, *conative*, as well as *cognitive* dimensions, emphasizing the role of interest and motivation in the process of conceptual change (Alsop & Watts, 1997). Hence, a class of uninterested and disengaged students would have little hope of having conceptual change.

Based on the conceptual change model, Hewson et al. (1998) have put forward four guidelines for teaching aimed at conceptual change: *1. Making ideas of the students and teachers explicit; 2. Metacognitive discourse; 3. Explicitly addressing and negotiating the status of ideas; 4. Explicitly justifying ideas and their status*. These guidelines constitute the *constructivist instructional approach* for effective NOS instruction (Abd-El-Khalick & Akerson, 2003). This constructivist pedagogy emphasizes discourse and public meaning making, which is based on the *social constructivist model* (Hewson et al., 1998; Mortimer & Scott, 2003; Ryder & Leach, 2008; Vygotsky, 1978) as well as the *personal constructivist model* (Appleton, 1997; Posner et al., 1982). According to the social constructivist model, concept learning starts from meaning making in the social plane through classroom discourse, and is then internalized into the psychological plane as personal meaning. To produce personal conceptual change, a teacher has to probe, work on, and challenge the ideas of students publicly and effectively. That makes *discourse* a crucial element in effective NOS teaching (Bartholomew et al., 2004; Beeth & Hewson, 1999), which is discussed in the subsequent section.

Classroom discourse and communicative approach

Grounded in the social constructivist model of learning, classroom discourse is at the heart of meaning making. For effective NOS instruction, the discourse has to be *reflective, epistemic* and *metacognitive* (Abd-El-Khalick & Akerson, 2003;

Bartholomew et al., 2004, Munby & Roberts, 1998). A discourse is reflective in the sense that students are guided to attend to and think through the NOS conceptions through questioning and activities. An epistemic discourse goes further to require students to evaluate and justify their arguments and ideas (Bartholomew et al., 2004, Munby & Roberts, 1998), while a metacognitive discourse have students reflect on the status, the underlying epistemological standards, and the consistency and generalization of their ideas (Abd-El-Khalick & Akerson, 2003; Smith et al., 2002). The meanings and key features of these kinds of discourse, however, have seldom been depicted clearly with actual classroom excerpts.

Closely related to the reflective, epistemic and metacognitive discourse is the *communicative approach* to the lesson. A framework has been developed by Mortimer and Scott (2003), and subsequently by Ryder and Leach (2008) to analyze the communicative approach of science teaching. The framework examines classroom talk in two dimensions: *interactive/non-interactive* and *authoritative/dialogic*. The interactive/non-interactive dimension refers to the extent students are allowed to express their ideas in class, whereas the authoritative/dialogic dimension indicates the extent students' ideas are heard, respected, explored, and worked on (Mortimer & Scott, 2003, p.34). An interaction of the two dimensions produces a total of four communicative approaches: *interactive/authoritative, interactive/dialogic, non-interactive/authoritative, and non-interactive/dialogic.* These communicative approaches are characterized by its *communicative patterns*. Interactive/authoritative communication tends to be in the pattern of *initiation-response-evaluation (IRE)* triads, while interactive/dialogic communication would have the pattern of *initiation-response-feedback-response-feedback (IRFRF).* Reflective, epistemic and metacognitive discourse would only occur when the teaching is interactive/dialogic in the pattern of IRFRF, while a non-interactive/authoritative classroom would be hardly reflective.

In addition to the above, Ryder and Leach (2008) have proposed two characteristics of classroom discourse for effective NOS teaching: *1. Make the NOS learning goals explicit and transparent to students; 2. Have frequent interchanges between contextualized and decontextualized NOS talk.* Making the NOS learning goals explicit throughout the lesson is important because students may easily attend to the context/content, rather than the NOS aspects during instruction. The science contents and the stories themselves are by nature more appealing to students than the abstrack NOS aspects. Reiterating and justifying the NOS learning goals throughout the class not only draw the attention of students to the NOS aspect, but also convey a message that NOS learning is as important as the science content/processes. This addresses the affective domain of the conceptual change model (Alsop & Watts, 1997).

NOS aspects can be addressed in a *contextualized* manner grounded in the specific contexts being discussed, or in a *decontextualized* manner in the form of general NOS statements. Ryder and Leach (2008) suggest regular interchanges between these two forms of NOS talk. General NOS statements tend to make NOS aspects abstrack and unintelligible to students. However, contextualized discussion falls short of limiting the NOS aspects to specific contexts, rather than to science in general. Thus, at key moments, the teacher has to tease out the NOS aspects embedded in the contexts for students to reflect upon, and then *generalize* these NOS aspects in the form of general NOS statements. These general NOS statements can further be re-illustrated by the same or other contexts. Such interchanges are more likely to effect conceptual change of students regarding their views towards authentic science. Taking Fleming's discovery of antibiotics as an example, these interchanges would appear as "Luck definitely helps him find the mould Penicillium [contextualized]. So we can see that scientific discovery sometimes needs luck, but luck is only for the 'prepared mind'[general]: You know how many years Fleming had devoted in searching for the anti-bacterial substances? [recontextualized]"

Another line of research focuses on the unique features of the scientific language. Findings from this area shed light on the classroom discourse for effective NOS teaching. One important piece of work in science discourse comes from Lemke's (1990) book *Talking Science*, in which he identifies a host of unique features of *scientific language*: *verbally explicit* (e.g. no pronoun and gestures), *universal* (abstrack and decontextualized, unchanging in time and place), *avoiding colloquial language* (e.g., I, we, you know, gonna), *avoiding humorous metaphors*, *using technical terms* (e.g., H_2O instead of water), *avoiding personification* (e.g., use of passive voice, no mention of the names of scientists), *ahistorical* (focusing on existing knowledge rather than how the knowledge comes), and *emphasizing causal explanations* (rather than descriptions only). Ostman (1998) calls this type of scientific language a *nature language*: full of assertions without considering the evidence and reasons, and the words such as "is", "consist of", and "contains" are frequently used, portraying science as truths confirmed by senses. Scientific explanations are also different from the everyday use of "explanation" for being *objectified, atomistic* and *mechanistic*.

The scientific or nature language as described above would communicate to students some *companion meanings* (Ostman, 1998): Science as an objective description of the world as it is, which is absolutely true and solely based on empirical evidence. These are *empiricist, realist* views of science. By contrast, what NOS educators aim to convey to students are the more *postpositivist, constructivist* views that science is a human endeavor to make sense of the world using creativity as well as evidence and logic, and is inherently tentative and revisionary (Lemke, 1990; Ostman, 1998; Zeidler & Lederman, 1989). The work of Zeidler and Lederman (1989) found that the orientations of the teachers' language: realist or instrumentalist, have significant impact on the NOS conceptions of students. Thus, in view of these findings, effective NOS teaching requires teachers to be highly sensitive to and aware of the companion meanings of the language they are using in class.

Summary

Drawing upon empirical findings of studies on NOS teaching and theoretical models for effective teaching and NOS teaching, a framework for NOS instruction is established, which encompasses the following characteristics:

1. NOS aspects are *explicitly* drawn to the attention of students.
2. NOS aspects are addressed in meaningful *contexts*: SSIs, historical case studies, scientific investigations, and moderately contextualized NOS activities. The contexts have to be made as similar to authentic science as possible, but are accessible and interesting to students.
3. Teaching is *constructivist* in the sense that prior NOS conceptions of students are elicited, challenged and worked on through classroom discourse, and the NOS aspects addressed are intelligible, plausible and fruitful to students.
4. The teaching is *interactive* and *dialogic*, and students are engaged in *reflective, epistemic,* and *metacognitive* discourse.
5. There are regular, seamless interchanges between contextualized and general discussions on NOS.

6. Classroom language is used carefully and accurately such that it does not tacitly convey inaccurate or naive NOS views.
7. The NOS learning goals are made explicit throughout the lesson.

This framework provides a provisional guide for the design of the study and the analysis of the teaching practices of the participants, but it is yet to be validated and enriched by the findings. A final framework as informed by the findings of this study will be made in the chapter of Conclusions.

KNOWLEDGE AND SKILLS NEEDED FOR NOS TEACHING

A number of factors have been identified to account for the inadequate emphasis on NOS in the science classroom (Abd-El-Khalick et al., 1998; Brickhouse & Bodner, 1992; Duschl & Wright, 1989; Hodson, 1993; Lederman, 1995). Many of these factors are *institutional constraints* imposed on teachers, including the expectations of the school and parents in covering science contents, pressure to prepare students for examinations, and peer pressure to follow the traditional, textbook-based teaching approach. While these factors are external to teachers, another realm of constraints comes from the attitudes of teachers toward NOS teaching. On the one hand, most teachers do not value NOS as an important goal for science teaching as science contents. On the other hand, most of them, particularly the inexperienced ones, have low self-efficacy in teaching NOS (Abd-El-Khalick et al., 1998; Brickhouse & Bodner, 1992; Lederman, 1995). They blame it for the lack of supports for NOS teaching, both professional training and instructional materials. Many teachers also do not think that students are interested in and capable of learning those NOS aspects, as these concepts are not much relevant to their science examination and too philosophical.

The above factors, however, are largely concerned with the intentions and beliefs of teachers intertwined with a host of external constraints, whereas the *ability* of teachers to teach NOS appears not to be given due attention. In the model of the requirements for teaching NOS proposed by Schwartz and Lederman (2002, p. 233), the *knowledge* base for NOS teaching is clearly distinguished from *beliefs* and *intentions* (Fig. 2.2). Although knowledge and skills intertwine inextricably with beliefs in the instructional decision making of science teachers as shown in the *Sociocultural Model of Embedded Belief Systems* of Jones and Carter (2007, p. 1074) (Fig. 2.3), the knowledge and skills are probably at the heart of the belief systems. Lederman (1999) has found that even the teachers with maximum flexibility in deciding what to teach do not incorporate NOS aspects significantly in their class. Moreover, given the central role of NOS unambiguously emphasized in many international science curriculum reform documents (AAAS, 1993; NRC, 1996), as well as the local science curricula (CDC & HKEAA, 2007a, 2007b), whether a teacher's attempts to teach NOS would be opposed by the school, parents, or colleagues remains arguable. Many studies found that even when teachers are required or intend to teach NOS, they fail to address the NOS aspects effectively (Bartholomew et al., 2004; Schwartz & Lederman, 2002). It is likely that science teachers simply have no ideas of how to start NOS teaching and/or have failure experiences with their attempts on NOS teaching, causing them to blame on a host of external factors and question the importance of NOS. Therefore, this section seeks to explore the knowledge and skills that teachers need to teach NOS effectively.

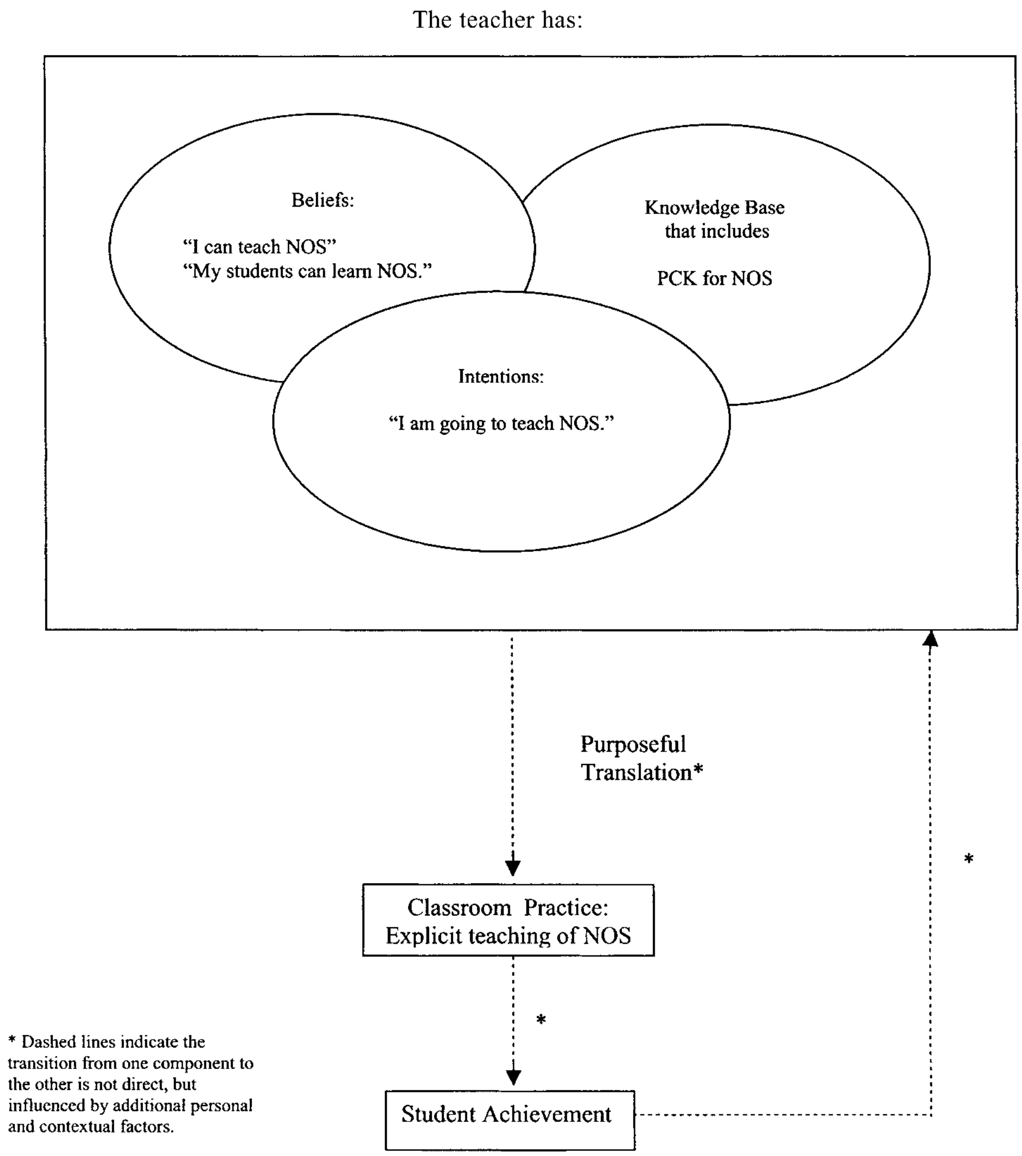

Figure 2.2 A model of the requirements for teaching NOS (Schwartz & Lederman, 2002, p. 233).

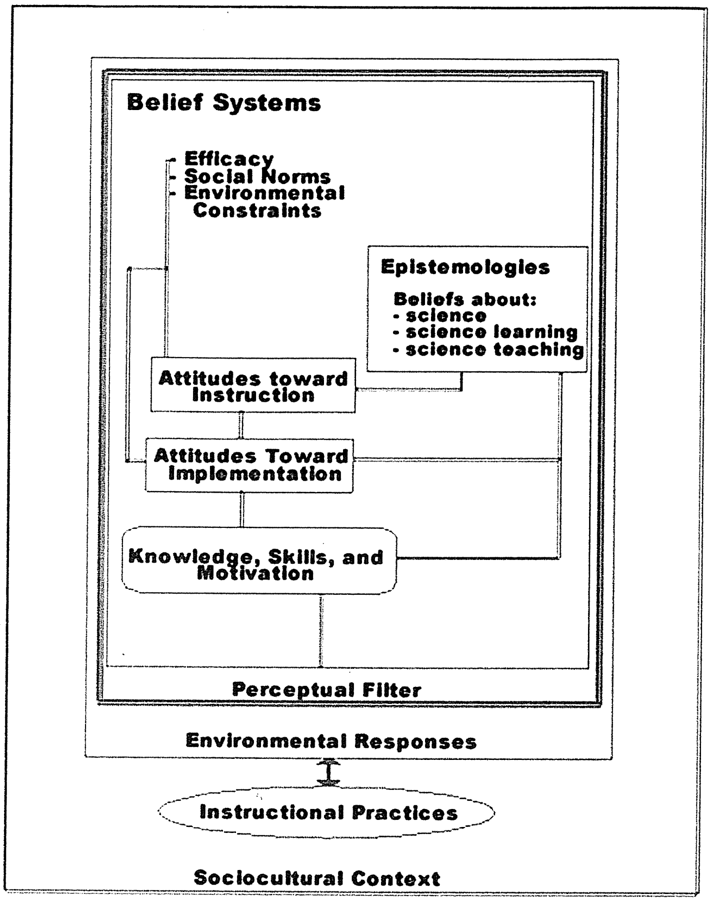

Figure 2.3 Sociocultural Model of Embedded Belief Systems for decision making in science instruction (Jones & Carter, 2007, p. 1074).

The concept of *pedagogical content knowledge* (PCK) helps delineate the knowledge bases necessary for effective NOS teaching. When NOS aspects are construed as a type of content knowledge, an effective teaching of NOS naturally demands appropriate PCK. PCK was first proposed by Shulman (1986), along with other knowledge bases necessary for teaching. PCK is the knowledge hardest to define precisely (Bishop & Denley, 2007) but a broad definition of PCK is “the transformation of subject matter knowledge into forms accessible to the students being taught” (Geddis, 1993, p. 675). Most scholars agree on two key elements of PCK: representing specific knowledge in ways comprehensible to learners, and understanding the difficulties and misconceptions of learners in learning such knowledge.

Schwartz and Lederman (2002) have depicted the PCK for NOS as the interaction among three domains of knowledge: NOS knowledge, subject matter knowledge, and pedagogical knowledge (Fig. 2.4). Abd-El-Khalick and Lederman (2000a) delineates the knowledge bases necessary for NOS teaching into knowledge of NOS, knowledge of pedagogy and PCK. They further explain the PCK for NOS as follows:

> knowledge of a wide range of related examples, activities, illustrations, explanations, demonstrations, and historical episodes…would enable the teacher to organize, represent, and present the topic for instruction in a manner that makes target aspects of NOS accessible to precollege students (p.692)

According to the PCK for NOS as described above, effective NOS teaching has to draw on a variety of knowledge and skills. These knowledge and skills are discussed in the following sections under three domains of knowledge: knowledge of NOS, pedagogical knowledge for NOS teaching, knowledge of the contexts for NOS teaching

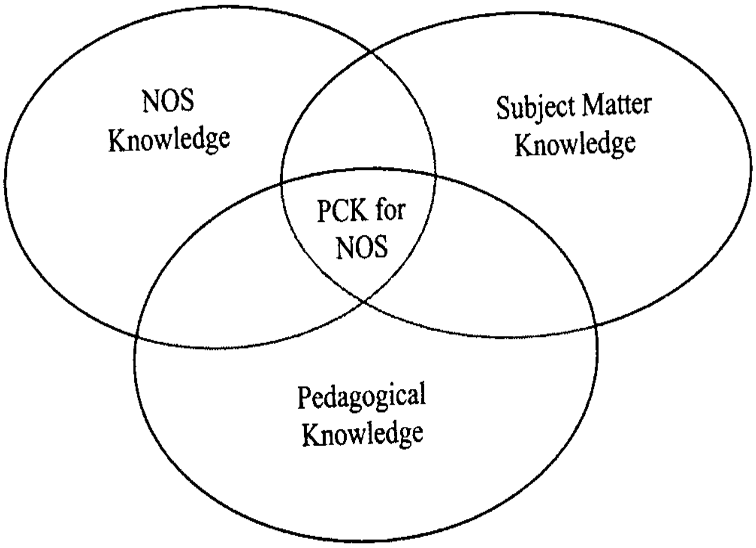

Figure 2.4 Pedagogical content knowledge (PCK) for NOS (Schwartz & Lederman, 2002, p. 232).

Knowledge of NOS

The importance of the NOS knowledge possessed by teachers to NOS teaching is self-evident and agreed upon by most NOS researchers (e.g., Abd-El-Khalick & Lederman, 2000a; Lederman, 2007; Schwartz & Lederman, 2002). However, empirical studies have revealed that science teachers, despite holding “informed” NOS understandings, do not directly and automatically *translate* their NOS understandings into teaching practice (Bell et al., 2000; Lederman, 1999; Lederman & Zeidler, 1987). There is a general conclusion that a good grasp of NOS aspects is a necessary condition, but far from sufficient, for effective NOS teaching (Abd-El-Khalick & Lederman, 2000a; Lederman, 2007). Apart from the intentions of teachers, the barrier to the translation of “adequate” NOS understanding into teaching practices is generally attributed to inadequate PCK or other knowledge bases necessary for NOS teaching (Abd-El-Khalick & Lederman, 2000a; Schwartz & Lederman, 2002). Bartholomew and others (2004) conclude that teachers' understanding of NOS is "only one factor among the five critical factors [Teacher's knowledge of NOS, teacher's conceptions of their own role, teacher's use of discourse, teacher's conception of learning goals and the nature of classroom activities]... our data lead us to doubt its centrality" (p. 678).

The above notions have simplified the NOS understanding necessary for NOS teaching. It is doubtful to claim that a teacher holds "adequate" NOS conceptions in light of the problematic validity of most of the NOS instruments (Lederman et al., 1998). These instruments usually consist of Likert type items in forms of general NOS statements, and/or open-ended short questions in limited contexts (e.g., VNOS). What these instruments reveal is at best a teacher's simple understanding of the general NOS statements. Effective NOS teaching, however, would require a teacher to have "more than a rudimentary or superficial knowledge and understanding of various aspects of NOS" (Abd-El-Khalick & Lederman, 2000a, p. 693). In some studies (e.g. Bartholomew et al., 2004; Schwartz & Lederman, 2002; Ryder & Leach, 2008), teachers' NOS conceptions are found surface and far from adequate to support effective teaching about NOS, despite their "adequate" performance in the quantitative NOS questionnaires. For effective NOS teaching, the general NOS understanding has to *transfer* to the specific contexts/contents used for NOS teaching in classrooms. Given that NOS understanding is highly context bound (Clough, 2005), the failure to teach NOS effectively likely stems from the inability of teachers to make such transfer (Abd-El-Khalick, 2001; Abd-El-Khalick et al., 1998; Akerson & Abd-El-Khalick, 2003; Lederman, 1999). This is evident in the study by Akerson and Abd-El-Khalick (2003), in which a teacher assessed holding "informed" NOS conceptions still failed to address the NOS aspects effectively in classroom. She needed extensive support from the researchers to help her activate and elucidate her *tacit* NOS understandings specific to the science contents. While the researchers conclude that NOS understanding alone is not sufficient for effective NOS teaching, whether such surface, tacit, and general NOS understanding should be construed as "adequate" remains arguable. But some researchers do not to take the issue seriously regarding the NOS understanding of teachers in NOS teaching. For instance, Schwartz and Lederman (2002) have found that a teacher could only address the subjectivity of science superficially with simple terms, but they still conclude that "to the extent that she understood subjectivity, she was *successful* in explicitly addressing NOS during the activity" (p. 218). Many studies simply do not examine how the NOS aspects are addressed by teachers in classroom but rely on the NOS instruments and interviews to judge the NOS understanding of teachers. This makes the roles of the NOS understanding of teachers in NOS teaching a largely neglected area in NOS research.

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Pedagogical knowledge for NOS teaching

Apart from the knowledge of NOS, effective NOS teaching has to be supported by certain pedagogies specifically required by NOS teaching, as well as the general pedagogy of teachers. As informed by the framework for effective NOS teaching, at the centre of the effective pedagogy for NOS is *constructivist* teaching and *reflective, epistemic, and metacognitive* discourse. Teachers need to possess the knowledge and skills to elicit and work on students' ideas toward science and construct meanings with them through extended discourse. In addition, teachers should be able to design and enact lesson plans such that the NOS aspects are represented effectively in an intelligible, plausible and fruitful ways to students.

The above requirements for the pedagogical knowledge of teachers are likely to associate with the teaching experience of teachers. In a study (Lederman, 1999), among the five biology teachers with 2–15 years of teaching experience, only the two biology teachers, with 14–15 years of teaching experience, exhibited strong NOS features in their classroom. The new teachers, who still struggled with classroom management and subject matter issues, tended to teach in a didactic, content-based manner. Their inadequate general pedagogy as well as a subscription to the transmissive model of teaching, made them unwilling and unable to teach NOS. Therefore, the general ability to organize and manage instruction is a *critical prerequisite* for NOS teaching, particularly for the new teachers (Lederman, 1999, p. 927). This is corroborated by a study (Ryder & Leach, 2008) involving seven *experienced* and *effective s*cience teachers. Provided with teaching materials from the researchers but without any professional support for NOS teaching, these teachers were able to address NOS aspects effectively in their teaching. Apart from the teaching resources provided, the success likely came as a result of their teaching experiences and effective pedagogies. This study can be contrasted with another study (Akerson & Abd-El-Khalick, 2003), in which a beginning teacher needed extensive support to address NOS in her classroom, even though she already had received extensive training on NOS instruction and had been assessed to have adequate NOS conceptions.

Nonetheless, the issue of pedagogical ability is not simply a matter of teaching experience, but pertains to the teaching orientation of teachers. A teacher's teaching behaviors are quite consistent and would change surprisingly little (Clough, Berg, & Olson, 2008). Even student teachers have been found holding strong initial orientations towards teaching and learning (Dana, McLoughlin, & Freeman, 1998). Therefore, how the existing pedagogical orientation of a teacher differs from the requirements of effective NOS teaching is a crucial but largely overlooked factor regarding NOS teaching. Smith and Neale (1989) have identified four teaching orientations: *discovery, processes, didactic/content mastery,* and *conceptual change*. Among these, the didactic/content mastery orientation appears to be most incongruent with NOS teaching that emphasizes reflective discourse, dialogic interactions and construction of meanings. Therefore, to teachers who hold this teaching orientation, NOS teaching would demand a *paradigm shift* in their fundamental pedagogical orientation. On the contrary, to those who are already practicing inquiry-based, constructivist pedagogy, an effective NOS teaching would more likely be within their reach. This factor creates differing demands for teachers to teach NOS effectively.

Knowledge of contexts for NOS teaching

Abd-El-Khalick and Lederman (2000a) have delineated the PCK for NOS as "knowledge of a wide range of related examples, activities, illustrations, explanations, demonstrations, and historical episodes….would enable the teacher to organize, represent, and present the topic for instruction in a manner that makes target aspects of NOS accessible to precollege students" (p. 692). This PCK for NOS draws on the knowledge of a variety of *contexts* for NOS teaching, including history of science, scientific inquiry, SSIs, NOS activities, and science subject matter. In the studies that teachers are required to design the contexts for NOS teaching on their own (Akerson and Abd-El-Khalick, 2003; Schwartz & Lederman, 2002), the NOS aspects tend to be inadequately addressed. By contrast, in another study (Ryder & Leach, 2008), in which the teachers were provided with extensive teaching resources, the teachers could address NOS aspects effectively even without any professional support for NOS teaching. This shows that the teaching resources provided to teachers may circumvent the requirements of the knowledge of contexts in designing and enacting NOS teaching. However, the relationships between knowledge of these contexts and NOS teaching are not substantially explored by empirical studies.

Summary

Past research on factors affecting a teacher's teaching about NOS largely focuses on the teacher beliefs and institutional constraints, leaving the knowledge and skills needed unexplored. The knowledge and skills pertaining to effective NOS teaching include the understanding about NOS, PCK of NOS aspects and general pedagogy. The teachers' understanding about NOS is a masked issue as teachers' NOS conceptions are wrongly assessed to be 'adequate' by the problematic NOS instruments. The PCK of NOS aspects is composed of a host of knowledge as well as a teacher's NOS understandings, including the knowledge about the contexts, examples and activities to illustrate the NOS aspects, and the difficulties students may face in learning these NOS aspects. The general pedagogy of a teacher is also a largely overlooked area for NOS teaching. Effective NOS teaching would demand a teacher to teach in a constructivist, interactive/dialogic manner, and engage students in reflective, epistemic and metacognitive dialogue. The existing pedagogical abilities and orientations of a teacher would create differing demands for effective NOS teaching. Lastly, supports for the teachers' development of these knowledge and skills are inadequate, both in teaching resources and model teaching, which has constituted the major barriers for NOS teaching.

SUPPORTS FOR NOS TEACHING

To what extent are science teachers supported to develop the knowledge and skills necessary for effective NOS teaching? Most of the science teachers, at least in Hong Kong, do not possess sufficient knowledge bases associated with NOS teaching: history, philosophy, sociology and even methodology of science. At best, they learn NOS teaching in the pre-service and/or in-service teacher education courses, which are often too short to provide them a good mastery of the NOS aspects, let alone the knowledge and skills to teach NOS effectively. Some may argue that teachers can develop the relevant knowledge and skills along with their teaching experience, like the general ability in teaching and understanding of subject matter. However, different from science subject matter, there are no *textbooks* for NOS teaching to support a novice teacher when beginning to teach NOS. As discussed earlier in this Chapter, quality NOS teaching resources in the contexts of science history, scientific inquiry and SSIs relevant to local science curricula and appropriate to particular groups of students remain largely unavailable, at least in Hong Kong. Science teachers, as a result, largely balk at the lack of supports and put aside the agenda to teach NOS. Without cumulative experiences, the knowledge and skills for effective NOS teaching would not develop, forming a deadlock for NOS teaching.

The above view is supported by a study (Abd-El-Khalick et al., 1998) in which the preservice teachers were modeled on how to use 15 generic NOS activities in a teacher education course. In the end, all of them failed to address the NOS aspects effectively in their actual teaching. They complained about the lack of NOS resources that were relevant to the contents they were teaching. This study has revealed that the provision of generic NOS activities is far from sufficient to support NOS teaching in actual classrooms as these activities do not fit into the curriculum that teachers are teaching.

As seen from the above discussions, extensive and appropriate NOS teaching resources targeting specific levels and subject contents of the science cuiriculum would be indispensable to initiate NOS teaching in actual classrooms (Akerson & Abd-El-Khalick, 2003). This is particularly important for beginning teachers because they largely lack automated routines in teaching and would be easily overwhelmed by the demands of NOS teaching. Only after a period of reflective practice might the teachers become sufficiently independent of the teaching resources, and capable of adapting and developing NOS teaching materials on their own. Examples of this stage can be found, though rarely, in some highly accomplished science teachers, such as the teacher studied by Beeth and Hewson (1999).

Support for effective NOS teaching, however, requires much more than teaching resources. A teacher who adheres closely to the teaching plan and enacts it mechanically may only achieve minimal outcomes. Effective NOS teaching is so interactive and dynamic that the teacher guidance notes never suffice to depict its process accurately. Teachers have to be shown how an effective teacher addresses the NOS aspects in actual classrooms (Akerson & Abd-El-Khalick, 2003; Bartholomew et al., 2004). Only in actual classroom teaching could all success elements of NOS teaching be presented in an integrated manner. Particularly powerful is that the exemplary teaching is done in the own classroom of the teacher and addresses the same content. This could allow teachers to realize that effective NOS teaching is manageable and achievable in the actual contexts of their work. In a study (Akerson & Abd-El-Khalick, 2003) in which a teacher, who initially failed to represent NOS aspects effectively in her class, got remarkable improvement after observing the exemplary teaching of the researcher on her fourth grade students. This study shows that modeling of NOS teaching plays a crucial role in promoting NOS teaching in classroom.

However, many of the professional development courses for teachers aimed at promoting NOS teaching do not pay sufficient attention to model teaching in the actual classroom context (e.g., Lederman et al., 2003). Often, these courses address the NOS aspects and NOS teaching separately in the non-classroom context, using decontextualized, content free NOS activities as examples. The instructors are usually university science educators who have no direct experience with NOS teaching in pre-college classrooms. In some in-service training programs (e.g., Bartholomew et al., 2004), the participants are asked to plan and teach NOS in their own classrooms, and then share experiences in the process. However, as most of them end up with ineffective teaching, unsurprisingly, the sharing of *failure* experiences would not have significant help in fostering their intentions and abilities of NOS teaching, except a sense of frustration and resistance toward NOS teaching.

Apparently, two significant deficits exist in the support provided for teachers regarding NOS teaching: appropriate teaching resources and exemplary teaching. These two aspects are interrelated in that appropriate NOS teaching resources must be derived from effective classroom teaching, while effective NOS teaching is supported by good teaching resources, at least at the beginning stage. Without these two types of support, efforts to promote NOS teaching would likely be futile.

Chapter Three

Methodology

This chapter describes and explains the methodology of the study. The research problems and the research questions are first highlighted. The research methods used to answer the research questions are then outlined, followed by the rationales and paradigm issues underlying these methods. The framework for effective NOS teaching established in Chapter 2 is briefly presented as it guides the research design and data analysis. The background of the participants and the contents of the NOS teaching course are also shown. After that, the processes of data collection are described in detail, particularly on the class observations and interviews. The two quantitative instruments used in this study are also discussed on their formats, items, reliability and validity. In this study, the classroom talks are analyzed quantitatively. The analysis framework is described and the coding of the classroom talks is defined with examples. The general process of data analysis is outlined. Drawing on the previous discussions, two crucial issues of research are then addressed: the credibility and limitations of the study. Finally, the ethical issues of the study are discussed.

THE PROBLEMS

Understanding NOS is widely recognized by science educators (Abd-El-Khalick et al., 1998; Duschl, 1990; Lederman, 2007; McComas et al., 1998) and by major reform efforts in science education (AAAS, 1993; NRC, 1996) as a perennial and central goal of science education. Despite nearly fifty years of efforts in implementing curricular reforms and developing professional teachers, the emphasis on NOS understanding has produced little impact: the NOS conceptions of both science teachers and students remain “inadequate” (Lederman, 2007, p. 869). Although substantial efforts have been exerted to improve NOS conceptions among science teachers, it is generally found that even science teachers that hold informed NOS conceptions do not automatically translate their understanding into practice (Bell et al., 2000; Lederman, 1999; Lederman & Zeidler, 1987). However, studies that have explored this problem have largely focused on the instructional intentions of teachers expressed in interviews (Abd-El-Khalick et al., 1998; Brickhouse & Bodner, 1992; Lederman, 1995). These studies on NOS teaching is superficial in the sense that they employ an “input-output” model (Lederman, 2007, p. 869), without conducting an in-depth exploration of the dynamics of NOS teaching in actual classrooms. Therefore, the teaching practices of NOS teachers and how effective these practices are, let alone which factors facilitate or impede their practices, remain largely unknown.

Given these problems with NOS teaching and its research, this study aims to conduct an in-depth examination of the complex processes of NOS teaching in actual classrooms in Hong Kong. The study is basically qualitative in its design; hence, the research questions are open and emergent. The general questions that guide the research directions and design are as follows:

1. How do a group of secondary science teachers in Hong Kong teach NOS in classrooms after attending a course on NOS teaching?
2. What is the discrepancy, if any, between the NOS conceptions of the teachers as assessed by the NOS instrument and as revealed by their NOS teaching?
3. What are the key characteristics of NOS teaching that are conducive to NOS

learning?

4. To what extent do the teachers demonstrate these key characteristics in their NOS teaching?
5. What knowledge and skills do science teachers need to possess in order to demonstrate these key characteristics of NOS teaching?

RESEARCH METHODS

Given the nature of the phenomena to study and the research questions, this study employs a *multiple case study* approach, examining the NOS teaching of eight science teachers in their actual classrooms. Although both quantitative and qualitative data were collected and used in the study, the research design principally follows the qualitative approaches.

The research questions of the study are answered with various methods as shown in Table 3.1. To examine how the teachers addressed NOS in class, the lessons were observed and videotaped, while the teaching materials were collected and analyzed. The whole lessons were transcribed, and the teacher and student talks were coded and counted for both qualitative and quantitative analysis. To identify the key characteristics of NOS teaching that are likely conducive to NOS learning, a framework was provisionally established through the synthesis of the literature and theoretical models (see Chapter two for details). This provisional framework guides the design of the study and analysis of the teaching, but it remains open to revisions based on the findings of this study. A final framework was developed, drawing on the provisional framework and the empirical data of the study.

Some methods were used to provide supplementary data to the study apart from class observations. The teachers were encouraged to assess students' NOS learning outcomes; however, the assessment was not standardized across all lessons but decided by individual teachers. The reasons are discussed in next section on the rationales for research methods. These empirical data help judge the effectiveness of the NOS teaching. On the other hand, the interviews and self-reflections of teachers provided information on the *intentions* and *beliefs* of the teachers regarding their NOS teaching. However, as the focus of the study is on knowledge and skills of teachers, information from the interviews and self-reflections of teachers were only drawn upon when deemed relevant. For example, some of the teachers' views could illuminate why they chose a particular approach and the pedagogical decisions they made in class. On the other hand, their feelings toward NOS teaching and the institutional constraints were deemed irrelevant to the research questions of this study. This makes the roles of the interview data secondary in this study as compared to some studies that placed heavy emphasis on teachers' views.

Two quantitative instruments were used in the study to assess the NOS understanding and constructivist pedagogy of the teachers. The assessment of teachers' NOS understanding with quantitative instrument helps answer the research question concerning with the discrepancies between teachers' NOS understanding, as assessed by quantitative instruments, and that revealed in actual teaching. The assessment of the constructivist pedagogy of teachers aims to examine how the original pedagogy of teachers affects their approaches to NOS teaching.

Table 3.1 Associations between research questions and research methods

Research questions	Research methods
1. How do a group of secondary science teachers in Hong Kong teach NOS in classrooms after attending a course on NOS teaching?	• Class observations and analysis of teaching materials • Quantitative analysis of classroom talk
2. What is the discrepancy, if any, between the NOS conceptions of the teachers as assessed by the NOS instrument and as revealed by their NOS teaching?	• Class observations and analysis of teaching materials • Assessment of NOS understanding of teachers with SUSSI before and after the NOS teaching course
3. What are the key characteristics of NOS teaching that are conducive to NOS learning?	• Construction of a provisional framework for NOS teaching from the literature and development of a final framework based on the empirical data of the study
4. To what extent do the teachers demonstrate these key characteristics in their NOS teaching?	• Class observations and analysis of teaching materials • Quantitative analysis of classroom talk • Evaluation of student learning outcomes by individual teachers
5. What knowledge and skills do science teachers need to possess in order to demonstrate these key characteristics of NOS teaching?	• Class observations and analysis of teaching materials • Quantitative analysis of classroom talk • Interviews and self-reflections of teachers • Assessment of NOS understanding of teachers with SUSSI before and after the NOS teaching course • Assessment of constructivist pedagogy of teachers by administering quantitative questionnaires to their students

RATIONALES FOR RESEARCH METHODS

As a qualitative research, this study is located in the *interpretivist* paradigm. A paradigm in research refers to the deeper philosophical issues underlying research methods, including its ontology, epistemology and methodology (Punch, 2009). Behind the issues over quantitative–qualitative approaches are deeper issues pertaining to the paradigms, principally between *positivism* and *interpretivism* or *constructivism* (Punch, 2009). Positivism assumes that there is single, objective reality and universal knowledge can be created through methods of science. In opposition to positivism, interpretivism or constructivism encompasses a variety of paradigms that assume the existence of multiple, constructed realities that their meanings are socially and experientially based, and that they have to be understood through multiple ways of knowing (Guba & Lincoln, 1994). This study acknowledges the assumptions of interpretivism in that it emphasizes the theoretical lens and perspectives that the researcher and teachers bring to classrooms in understanding the complex interactions between teachers and students during NOS teaching. Therefore, what counts as effective NOS teaching, as well as what knowledge and skills that affect a teacher's practice, are necessarily interpretivist as they are based on the relatively subjective judgments of the researcher and the self–reflections of the teachers. In addition, the researcher believes that only with multiple data sources and multiple ways of data collection could the complex behaviours of teachers and students in classroom be fully captured.

This study follows the qualitative approaches based on a pragmatic consideration of the question–method compatibility (Punch, 2009). As NOS teaching in classroom is largely an unexplored phenomenon without obvious theories to guide its research, this study aims at in depth *description* and *understanding* of this phenomenon. This aim justifies the use of qualitative methods that seek to describe, understand and interpret human experience, rather than to verify theory as in quantitative research (Lichtman, 2009). On the other hand, the teaching in classroom, particularly NOS teaching that emphasizes interactions and dialogues with students, is necessarily dynamic, complex and contextual, involving interactions of a number of human and contextual factors. Thus, a study of NOS teaching necessitates the use of qualitative methods that are dynamic, multiple, holistic, in depth and naturalistic (Lichtman, 2009). In this study, multiple sources of data pertaining to NOS teaching were collected using different methods, such as class observations, interviews of teachers, and self-reflections of teachers. These data provide in depth, holistic descriptions and accounts of the NOS teaching in its natural settings.

A case study approach best suits the study of NOS teaching in actual classrooms, because it allows full, in depth understanding of NOS teaching in its natural settings (classrooms), recognizing its wholeness and context (Stake, 1994). This study is an *instrumental case study* (Stake, 1994) that aims to illuminate the practice and theory regarding NOS teaching. The cases, the eight science teachers, are typical of new science teachers in Hong Kong; hence, an in depth study of their attempts at NOS teaching may have important implications for NOS teaching of teachers in Hong Kong. Besides, a *multiple case study* on eight science teachers allows the findings to be compared both within and across cases. As the teachers varied in their approaches to NOS teaching, the comparisons across cases can shed light on the relative effectiveness of various approaches, as well as on how personal variables of teachers and the contextual variables affect the teaching. In addition, multiple cases allow for generalization, although at a limited scope, by identifying common themes across cases. The problem of generalizability of case study design will be discussed further in the section of Limitations.

In this study, the collection and analysis of data use both qualitative and quantitative methods, making the study a *mixed methods design*. This approach has been criticized for the incompatibility of the worldviews underlying the qualitative and quantitative methods, namely, between positivism and interpretivism (Reichardt & Rallis, 1994). However, with growing interest in mixed methods research, some argue that the incompatibility is merely a result of the false dichotomy between the qualitative and quantitative methods and worldviews (Creswell, Goodchild, & Turner, 1996; Reidchardt & Cook, 1979). The mixed methods approach gradually gets its support from the philosophy of *pragmatism* (Tashakkori & Teddlie, 1998). Pragmatism as the paradigm underlying mix methods research asserts the prime importance of what "works" to answer the research questions. Qualitative and quantitative methods have their respective strengths and limitations. It is the research questions, rather than the paradigms, that determine the methods needed, either qualitative, quantitative, or mixed.

Therefore, based on this pragmatist worldview, this study seeks to answer the research questions with both qualitative and quantitative methods where deemed appropriate. The methods are principally qualitative: class observations, self-reflections and interviews, whereas the quantitative surveys provide supplementary data to triangulate the findings of the qualitative data and help address some other research questions. Hence, this study is an *embedded mixed methods design* (Creswell, 2008) where the primary methods and data are qualitative. Quantitative data were collected using two instruments: the Understanding of Science and Scientific Inquiry (SUSSI) (Liang et al., 2006) and the Constructivist Teaching Questionnaire (Tenenbaum et al., 2001). The Constructivist Teaching Questionnaire is needed to survey the views of a large number of students on the constructivist pedagogy of their teachers in ordinary lessons. The quantitative data are used to triangulate the class observations and to shed light on whether the original pedagogical orientations of teachers are crucial in NOS teaching. SUSSI was used because this research aims to explore if there are any discrepancies between the NOS conceptions of teachers, as measured by NOS instruments, and those revealed by their teaching in classrooms.

This study evaluated the process of NOS teaching with a theoretical framework, rather than with empirical assessments of the NOS learning outcomes of students. The rationales behind this decision are manifold. First, the validity of the standardized NOS assessment instruments is doubtful (Lederman et al., 1998). Second, the gains of NOS understanding among students in one or two lessons would be hardly detectable with an instrument. Third, a valid NOS assessment has to be in line with the teaching of NOS. However, as a naturalistic research, this study allows teachers to devise their NOS teaching suited to their own curricula and students. This made standardized assessment of the learning outcomes of the students from the eight teachers impossible. Therefore, in this study, NOS teaching was mainly judged by its *processes* theoretically rather than its *products* empirically. Nonetheless, the participants were also encouraged to devise their own evaluations of learning outcomes appropriate to their lesson objectives and students. Some of the participants executed systematic, written evaluations of the NOS conceptions of their students, while some participants just interviewed a few students after the lessons. These data corroborated class observations, helping shed light on the effectiveness of NOS teaching.

PROVISIONAL FRAMEWORK FOR NOS TEACHING

At the heart of this study is the framework for characterizing NOS teaching, which was used initially and provisionally to guide the study design, as well as the data collection and analysis. The framework was drawn from the extensive literature on effective teaching models in general and effective NOS teaching in particular. The two most popular and well-studied components of NOS teaching approaches are the *explicit/implicit* approach and the *contexts* used to teach NOS. The *explicit* approach can improve the NOS conceptions of students, whereas the *implicit* approach is generally ineffective (Abd-El-Khalick & Lederman, 2000a, p. 692; Lederman, 2007, p. 869). Hence, the first characteristic for NOS teaching seems obvious: explicitly draw the attention of students to NOS aspects, instead of letting students implicitly experience what science is by only engaging them in scientific inquiry activities. On the other hand, the NOS literature has shown that NOS aspects can be addressed in a variety of contexts: decontextualized NOS activities, the history of science, scientific inquiry activities, socioscientific issues, and science content. These contexts, when used explicitly, can produce positive outcomes in understanding NOS (Abd-El-Khalick & Lederman 2000a). However, these contexts have their respective strengths and limitations (e.g., Clough, 2006; Khishfe & Abd-El-Khalick, 2002; Sadler et al., 2004; Stinner et al., 2003). Effective NOS teaching, hence, has to attend to these issues.

Given the widely known naïve NOS conceptions held by students, NOS teaching is best informed by constructivist perspectives and conceptual change models of teaching and learning. Thus, the framework draws heavily on both the *personal constructivist model* (Appleton, 1997; Posner et al., 1982) and the *social constructivist model* (Hewson et al., 1998; Mortimer & Scott, 2003; Ryder & Leach, 2008; Vygotsky, 1978). The personal constructivist model emphasizes four conditions for personal conceptual change: *intelligibility, plausibility, fruitfulness,* and *dissatisfaction* (Hewson & Thorley, 1989), whereas the social constructivist model emphasizes public meanings making through epistemic, metacognitive, and reflective discourses. To help analyze classroom interactions and discourses, the framework borrows the analytical tools developed by Mortimer and Scott (2003), in which the *communicative approach* of teaching is analyzed in two dimensions: *interactive/non-interactive* and *authoritative/dialogic*. An interactive/dialogic communication in class is deemed a key characteristic of NOS teaching.

Effective NOS teaching should also pay due attention to *contextualized* NOS aspects that are grounded on specific contexts, and *decontextualized* NOS aspects that are presented with general NOS statements (Ryder and Leach, 2008). Frequent interchanges between contextualized and decontextualized NOS discussions are considered a condition for effective NOS teaching, whereas decontextualized NOS discussions alone is undesirable.

Hence, in this study, the framework for NOS teaching includes the following components: explicit approach and convincing contexts, constructivist pedagogy, classroom discourses and communicative approaches. This framework, however, is provisional and open, and is yet to be validated and enriched by the findings of this study. A final framework as a product of this study is presented in the chapter of Conclusion.

PARTICIPANTS

The eight participants of this study participated in a two-month NOS teaching course as part of their pre-service/in-service professional development course for teachers. The sampling was purposive because the participants were considered typical science teachers in Hong Kong and they taught NOS using a variety of approaches.

Although most of them are inexperienced teachers holding biology-related degrees, one (KWM) is a physics teacher with over 15 years of teaching experience. Most of the teachers possess strong academic backgrounds, holding master or even doctoral degree in science. However, all of the participants have not attended any classes on NOS conceptions or NOS teaching before the course. Table 3.2 shows the biographical information of the participants.

Table 3.2 Biographical data of the participants

Name (Pseudo –nym)	Gender	Age range	Teaching experi- ence (Year)	Major subject taught at school	Academic qualifications
CYT	F	20-30	3	Biology	BSc in applied Biology and Biotechnology
NWY	F	20-30	2 (Evening school)	Biology	BSc and MPhil in Biology
LKY	F	20-30	1	Biology	BSc in Food and Nutrition
PHF	M	20-30	1	Biology	BSc in Animal and Plant Biotechnology, MPhil in Cancer Biology
MPY	F	20-30	2	Biology	BSc in Biology
WTY	M	20-30	1	Biology	BSc in Animal and Plant Biotechnology Biology, MPhil and PhD in Molecular Immunology and Virology
WYC	M	20-30	2	Biology	BSc in Biology, MPhil in Chinese Medicine
KWM	M	40-50	15	Physics	BSc in Physics, Diploma in Education

NOS TEACHING COURSE

All participants received no prior instruction about NOS and NOS teaching; hence, the teaching course on NOS was likely the only input the participants received. This necessitates a detailed description of the course contents because the course may constitute an important consideration in the explanation of participant's teaching practices.

The course, taught by the researcher, lasted for two months, with a total of eight 2-hour sessions. The course aimed to make participants understand NOS aspects, the importance of NOS in science education, and most importantly, how to teach NOS effectively. The contents and objectives of the course are listed in Table 3.2. Rather than talking about the principles of teaching NOS, a variety of specific examples were used to illustrate ways of addressing NOS aspects in the classroom. Many of the teaching plans were biology related; hence, the participants found the topics relevant or useful to their teaching practice. In the classes, the participants played the role of students and experienced the teaching processes, while the researcher provided a model of effective NOS teaching. After each model teaching, a class discussion was held to reflect on the teaching plan and the teaching strategies employed, as well as the addressed NOS conceptions. It is hoped that this approach, which integrates the learning of NOS conceptions and NOS teaching through specific examples, would be effective in modeling teaching about NOS within a short period. Nonetheless, some distinctive features of NOS teaching would need extensive experiences to develop. For example, although the course instructor had shown the teachers how to engage students in reflective dialogues and emphasized its importance in NOS teaching, it is not expected the teachers would be able to do that competently just after the course.

Table 3.3 Contents and objectives of the NOS teaching course

Contents	Objectives
General introduction to the NOS aspects, its history and roles in science education	Importance of NOS to science teaching and learning
Teaching NOS using the history of science: • Discovery of the bacteria H. Pylori as the main cause of peptic ulcers • Controversy over the causes of dinosaur extinction • Discovery of the DNA structure	• NOS conceptions embedded in the historical cases • How to explicitly address NOS aspects using historical case studies
Infusion of NOS aspects into the topic of photosynthesis	How to address NOS aspects in ordinary subject matter—an infused approach
Addressing NOS aspects while interpreting experimental results: • How pH values affect amylase activities using the starch agar plate • How catalase activities are affected by the concentration of hydrogen dioxide solutions	How to explicitly address NOS aspects while conducting post-lab discussions with students during everyday science investigations in school
Addressing theory-laden observations using gestalt switches and other activities	How to address NOS aspects using content-free, decontextualized NOS activities
Interpretation of dinosaur footprints	How to explicitly address NOS using moderately contextualized NOS activities
How classroom language implicitly shapes NOS conceptions among students—scientific language	the implicit NOS meanings conveyed by classroom language

DATA COLLECTION

Data were collected using multiple methods over a period of three months toward the end of 2009. At the beginning and the end of the NOS teaching course, the

NOS preconceptions of participants were assessed with SUSSI. In the 2-month NOS teaching course, the participants learned about NOS conceptions and how to teach these conceptions effectively in class. At the same time, the participants were asked to administer the Constructivist Teaching Questionnaire to their students. Throughout the course, the participants were encouraged to attempt NOS teaching in their classes and to keep an online reflective journal on their experiences in teaching and learning NOS. The participants also shared and exchanged ideas in class and in an online forum.

At the end of the course, every participant was required to plan and teach at least one lesson addressing some NOS aspects learned. The participants were allowed to decide on the topics and approaches of their NOS teaching, as well as the means of evaluation of the learning outcomes. This is to ensure that the normal teaching schedules of the teachers were not disrupted. In addition, it allows an examination of their planning and decision making processes. All the lessons were observed by the researcher and videotaped. Field notes were taken during class observations using the semi-structured Class Observation Protocol (see Appendix 3).

A post-lesson interview of the teacher was conducted on site by the researcher. The interviews were semi-structured as guided by the Interview Protocol (see Appendix 4) and were audiotaped. In the interviews, the teachers were asked how they perceived their teaching, the importance of NOS to them and their students, as well as the challenges they faced in their NOS teaching attempts. The interviews usually lasted for 30 minutes to an hour.

All the documents related to NOS teaching were collected, including teaching plans, handouts, and worksheets. Finally, each teacher had to write a self-reflection on his/her experiences in planning and teaching NOS, and evaluate the effectiveness of their lessons with evidence. The teaching materials and student assessments, together with the audio and video recordings, were included in the DVD ROM of the addenda.

Student Understanding of Science and Scientific Inquiry (SUSSI)

The NOS understanding of participants was assessed (pretest and posttest) using the 2nd version of SUSSI (Liang et al., 2006) (see Appendix 2). The instrument consists of both Likert-type items and open ended questions that assess the views of the participants on six major NOS themes: *observations and inferences, changes in scientific theories, scientific laws vs. theories, social and cultural influences on science, imagination and creativity in scientific investigations, and methodology of scientific investigations*. Each theme is assessed by four Likert-type items and one open-ended question. The open-ended items compensate for the limitations of the fixed-response quantitative instrument. The instrument was empirically developed using qualitative methodology, and it has been validated by hundreds of pre-service science teachers in the United States, China, and Turkey. For Chinese teachers, the reliability alpha is 0.68.

Constructivist Teaching Questionnaire

The existing pedagogical orientation of teachers is one of the major determinants of their success in NOS teaching. Among the various pedagogical orientations, the constructivist pedagogy appears to be most congruent to what effective NOS teaching requires. Therefore, both the participants and their students were assessed by an instrument to evaluate the extent that the teaching of the participants captures the features of constructivist teaching (see Appendix 1). The questionnaire was developed by Tenenbaum et al. (2001) in two stages: firstly, 12 experts in constructivist teaching were consulted to identify the essential features of constructivist pedagogy; and secondly, based on the characteristics of constructivist pedagogy identified in the first stage, a quantitative questionnaire was developed, which was further reduced, tried out, and validated with university students in Australia. Finally, 150 items were progressively reduced to 27 items using various statistical analyses, ensuring their reliability and validity. Using factor analysis, seven factors were identified from the items, which jointly accounted for 69.5% of the variance. In addition, each factor has high internal consistencies (α= 0.72-0.87) and small-to-moderate correlations with one another. These seven factors are (1) arguments, discussions, and debates; (2) conceptual conflicts and dilemmas; (3) sharing ideas with others; (4) materials and resources targeted toward solutions; (5) motivation toward reflections and concept investigation; (6) meeting the needs of students; and (7) making meaningful, real-life examples. The questionnaire was further administered to 271 students, and a confirmatory factor analysis showed that six of the factors are highly correlated, with the exception of the factor "conceptual conflicts and dilemmas," which Tenenbaum et al. (2001) considered to be a more important feature of constructivist pedagogy than the other factors.

Quantitative analysis of classroom talk

Classroom talk among teachers and students were further converted into quantitative data to help judge the communicative approach taken by teachers. On the teaching transcripts, the talk of teachers and students was first coded according to its nature (see Table 3.4 for the definitions of each kind of talk). The types and definitions of classroom talk were developed through an iterative process of examining the teaching transcripts and defining new codes. Thereafter, the numbers of different kinds of talk were counted and the frequency calculated (see Table 4.6). The coding was made by the researcher of this study. To enhance the validity of coding, a sample coding of two transcripts was independently accomplished by the researcher and another science educator. Nearly 85% of the coding was in agreement and the remaining disagreement was resolved through discussions.

Table 3.4 Definitions of different types of classroom talk

Types of classroom talks	**Definition**
	Student talk
Simple/elaborate student talk	An *episode with more than ten words is considered an elaborate talk.
In response to the teacher/classmates /on own initiative	This denotes whether students are directly responding to teachers, their classmates, or talk on their own initiative. Unless otherwise coded, the default for all kinds of student talk is in response to teachers.
Discussing in groups	Students discuss in small groups, as required by the teacher. A whole group discussion is counted as one instance.
Asking teacher questions	Students take the initiative to ask questions, not in response to questions posed by teachers.
	Teacher talk
Simple/elaborate teacher talk	An *episode with more than ten words is considered an elaborate talk.
Closed questions/open questions	Closed questions are those that can be answered with *yes/no,* or a choice from a few options. Open questions, which often start with *how, why, and what*, are those that require *constructed responses*.
Elaboration questions	These are questions that follow students' responses, asking for further clarification or elaboration of presented ideas.

Table 3.4 Definitions of different types of classroom talk (continued)

Reflective questions	These are questions that explicitly ask students to think about NOS aspects.
Metacognitive questions	These are questions that follow students' responses when they are made to *think about their own thinking*—justifying, evaluating, and reconciling the inconsistency of their ideas.
Class surveys	Teachers conduct simple surveys to solicit the ideas of the whole class on particular issues.
Generalizations	Teacher explicitly generalizes NOS aspects extracted from contexts.
Illustrations	Teacher further illustrate NOS aspects just learned in class using other examples from authentic science.
Significance	Teachers explicitly emphasize the significance of NOS learning as an important goal in science learning.

**An episode is a continuous talk by one person.*

Note: The different kinds of classroom talks are not mutually exclusive. For instance, a metacognitive question can also be a reflective and open question. In such cases, the talk is categorized to the most specific kind. At times, an episode may be double coded.

The following two excerpts from this study illustrate how the classroom talks were coded according to the above definitions:

T: Do you know how scientists decide on whether claims are believable? These claims have their arguments, but why is it that other scientists do not accept them? [*reflective question*]

S: Not holistic… [*simple student talk*]

T: What do you mean by "not holistic"? Take pollen allergy for example? [*elaboration question*]

S: The pollen will dissolve in water… S1: not perfect… S2: unreasonable…

T: Why is that very unlikely? [*elaboration question*]

S: Why is it that dinosaurs did not become extinct earlier? [*student simple talk on his/her own initiative*]

T: Do you think the claim that dinosaurs disappeared about 65 millions years ago is 1. an absolute fact, 2. a reasonable inference, or 3. a speculation? Raise your hand if you think the answer is 1? Who thinks the answer is 2? What about 3? [*class survey*]

DATA ANALYSIS

The study produced three quantitative databases from the SUSSI, the Constructivist Teaching Questionnaire, and the analysis of classroom discussions. These data *supplemented* findings from the analysis of qualitative data (e.g., teaching transcripts, field notes, interviews, teaching documents, and self-reflections). As explained earlier, qualitative data were given greater weight during the analysis.

The main analysis focused on the teaching practices of participants. The teaching transcript of each participant was first read through while the corresponding teaching video was shown so that some important non-verbal communications in class could be added to the transcript. Thereafter, each teaching transcript was segmented according to the main purpose of each teaching episode, such as *introduction, telling the story, and discussing NOS aspects*. Then the talk by teachers and students was coded (Table. 3.4). After the preliminary organization and coding of the transcripts, an in-depth examination of the overall teaching was conducted for evidence of effective/ineffective NOS teaching practices. The examination focused particularly on the overall teaching approach, the accuracy and intelligibility of NOS aspects addressed in class, and how the ideas of students were engaged and worked on. Finally, an in-depth profile of the NOS teaching of each participant was generated. Based on these profiles and other supporting documents and data sources (quantitative data, teaching plan, teaching materials, self-reflection, interviews, etc.), themes emerged inductively to account for the teaching practices of participants. The entire process was iterative and cyclical, as suggested by Creswell (2008, p. 244). The themes identified from each case were then triangulated among one another to look for common themes that can account for the NOS teaching practices of all the participants.

CREDIBILITY

The methods of data collection and data analysis of this study were largely qualitative; hence, the traditional terms of validity and reliability are replaced by *credibility* (Creswell, 2008). In this study, credibility was assessed in terms of authenticity, comprehensiveness, honesty, depth, and meaningfulness to the respondents (Cohen, Manion, & Morrison, 2000). First of all, the study is highly authentic because teachers taught NOS to their own students in their own classrooms as a part of their ordinary teaching and learning at schools. The analysis of the classroom teaching was in depth and thorough; the teaching videos and transcripts were analyzed microscopically in an iterative manner. The *triangulation* of data also added credibility to the findings. Data were obtained from multiple sources (the eight participants and their students), in different nature (both quantitative and qualitative data), and through different ways (interviews, class observations, questionnaires, teaching materials, self-reflections, and online forum). The codes and themes generated from one case or one data source were checked against multiple sources and data types across cases until theoretical saturation

(Glaser & Strauss, 1967), thus ensuring their accuracy and trustworthiness.

To enhance the credibility of the judgments of the NOS teaching approaches of participants (Table 4.5), the coding of classroom talk (Table 4.6), and the determination of their communicative approaches (Figure 4.1), four cases were independently analyzed by the researcher and another science educator. In general, sufficient agreement between the two analyzers was reached. In addition, this science educator helped review the overall study, including its design, data collection, and most importantly, the data analysis to ensure its credibility. This science educator was a renowned honorary associate professor specialized in NOS teaching.

Member checking is important to ensure the accuracy of data and the appropriateness of the interpretations (Guba & Lincoln, 1989). In the post-lesson conferences, the teachers were asked to comment on the field notes and the comments of the researcher. Later, they were also provided with the transcripts and the analysis of their teaching to review and comment. No participants expressed major disagreements with the descriptions and accounts of their teaching, and they even supplemented some additional information to explain their practices.

The teaching videos were transcribed directly from spoken Chinese (Cantonese) to English. The transcription was conducted by a translator who excelled in both English and Chinese. The accuracy of the transcription and translation was checked by the researcher; the transcripts were checked word by word against the videos. In addition, five random excerpts from the transcripts were sampled for *reverse translation*, and the meanings of the texts were generally consistent. Nonetheless, when analyzing the teaching episodes that were significant, the researcher watched the videos directly to ensure accurate judgments. Hence, the potential errors in translation and transcription could be largely circumvented.

As the main instrument for the collection and interpretation of data, the researcher must reflect on his own perspectives. The researcher has held some provisional ideas with regard to the problems with NOS teaching. First, impediment to NOS teaching mainly pertains to the ability of teachers rather than their intentions. Hence the study seeks to examine the knowledge and skills a teacher needs to teach NOS. Second, NOS understanding of teachers is at the heart of the ability to teach NOS effectively. However, the NOS conceptions of teachers as assessed by the NOS instruments in most studies are largely invalid. Hence, the study judges the NOS understanding of teachers from their class teaching rather than through NOS instruments. Third, effective NOS teaching has to be constructivist and engaging. These notions motivated the researcher to conduct this study, and guided the research design. Nonetheless, the researcher keeps reflexive on these notions during data collection and analysis, and is sensitive to alternative explanations emerged from the data.

LIMITATIONS

One major criticism to qualitative research in general, and case study research in particular, is its generalizability. Punch (2009) argues that, while a case study can be valuable in its own right (intrinsic case study), case studies can also “generalize” their findings by *conceptualizing*. Case studies allow an in-depth study of complex behaviours, by which understandings and concepts can be developed to illuminate further research. This is what Stake (1994) refers to as the *instrumental case study*. This study is an instrumental case study that seeks to conceptualize NOS teaching of the teachers, identify the practices that are effective or not, and explore the knowledge and skills that affect NOS teaching. Therefore, the findings of the study are generalizable in that sense. In addition, as a multiple case study, this study seeks to identify common themes across the eight teachers to make the findings more generalizable. However, as the participants were largely new biology teachers in Hong Kong, the findings are likely limited to teachers in that background.

Another limitation of the study stems from the perspectives and values the researcher brought to the study in the analysis and evaluation of the NOS teaching. The framework for effective NOS teaching, despite drawing upon extensive empirical findings from the NOS literature, is theoretical and *a priori* to some extent. This, coupled with the inevitable subjectivity of the evaluator, jeopardizes the credibility of the findings of the study. Nonetheless, as a case study research, these findings function to illuminate further research and are subject to validation.

As a case study research, this study, however, falls short of not having sufficiently intensive engagement with the NOS teaching of the participants; only one or two lessons of each participant had been observed and studied. This was a result of the practical constraints that the participants had to address their existing teaching schedules and find the appropriate topics to infuse the NOS elements. In addition, they needed to put in huge efforts in preparing for the NOS teaching. Therefore, they were allowed to decide on the approaches, topics and numbers of their attempts at NOS teaching. Some participants did make several attempts until they were sufficiently confident to be observed. To compensate for this inadequacy, a total of eight teachers were studied in order to increase the total number of lessons observed. However, the credibility of the findings within cases is still jeopardized. Besides, this also made the study unable to trace the progress of NOS teaching of the participants when they accumulate experience in it.

As a mixed methods study, the compatibility of the qualitative and quantitative data is an inherent issue. The NOS understanding and constructivist pedagogy of the teachers were evaluated by both the quantitative questionnaires and observations of their teaching. When the findings by the two methods are contradictory, decisions have to be made on the precedence of the data. In this study, qualitative data are construed as more credible than quantitative data based on the interpretive worldview.

ETHICAL ISSUES

All participants in this study are teachers participating in a teacher education course on NOS teaching. The teachers were clearly told about the research objectives, and they were given the discretion to choose to participate in the research or not, or to withdraw at any time after joining. The teachers were assured that their decisions would not influence their grades in the course, that data collected would be used for research purposes only, and that the research would not influence the assessment of their performance in the course.

This study seeks to enhance participants' views on NOS and to model the teaching methods of participants for effective NOS teaching; hence, the participants would definitely benefit, rather than suffer, from the study. The participants would improve their understandings about NOS and teaching repertoire through learning in the course and through feedback from the researcher during post-lesson conferences, interviews, and informal talk. A detailed profile of the analysis of their NOS teaching was provided as a formal feedback. In addition, the data collection process was naturally integrated with the teaching and learning activities of the course; hence, no additional load was imposed on the participants.

To refrain from interfering with the normal learning process of the students of the participants, the participants were asked to plan NOS lessons within the existing curricula and contents. The teachers had the flexibility to determine when and how much class time they would devote to NOS teaching. Consequently, most of the participants only taught NOS in one or two classes.

The participants obtained consent from their schools to videotape their lessons. The teaching videos and related documents were kept confidential; the anonymity of the teachers, schools, and students was guaranteed in the report.

Chapter Four

Findings and Analysis

INTRODUCTION

In this study, both quantitative and qualitative data were collected from eight studied cases. Quantitative data came from two instruments: the Understanding of Science and Scientific Inquiry (SUSSI) questionnaire (Liang et al., 2006), which was administered (pretest and posttest) to the participants to assess their understanding of NOS, and the Constructivist Teaching Questionnaire (Tenenbaum et al., 2001), which was administered to the participants and their students to evaluate the features of constructivist pedagogy in the ordinary lessons of the participants. Data pertaining to the NOS teaching methods of the participants were mostly qualitative in nature. The data included teaching videos and their transcripts, audiotaped interviews, lesson plans, teaching materials, self-reflections, and evaluations on learning outcomes. A quantitative analysis on the classroom talk of the participants was conducted to provide evidence on their communicative approaches. A complete set of the qualitative data is included in the DVD-ROM of the addenda. In this chapter, only selected teaching episodes are shown along with the data analysis.

The data and the data analysis are presented together in the chapter. First, an overview of the NOS teaching of the participants is given. Thereafter, various factors that affect NOS teaching are explored, including the NOS understanding of participants, the general teaching approach of participants, the communicative approach of participants in class, and the use of constructivist pedagogy. The analysis is both descriptive and evaluative, drawing on the framework for effective NOS teaching presented in Chapter 2. Finally findings from these analyses are synthesized to explore the knowledge and skills that affect the ways teachers conduct NOS lessons.

NOS TEACHING BY INDIVIDUAL PARTICIPANTS

The lessons of the participants on NOS teaching were observed, videotaped, transcribed, and analyzed. Background information on these lessons is presented in Table 4.1, whereas the teaching approaches, contents, and targeted aspects of NOS in the lessons are summarized in Table 4.2.

Table 4.1 Background information of the NOS teaching lessons of the participants

Participant	Grade level of the students	Ability of the students*	Subject	Class size	Language of instruction
CYT	7	high	science	33	Cantonese
NWY	10	low	biology	35	Cantonese
LKY	11	medium	biology	18	Cantonese
PHF-1	11	low	biology	35	Cantonese
-2	11	low	biology	34	Cantonese
MPY-1	11	medium	biology	43	Cantonese
-2	13	medium	biology	10	Cantonese
WTY	11	high	biology	40	English
WYC	11	high	biology	39	Cantonese
KWM	10	medium	physics	38	Cantonese

* The ability of the students is determined by the bandings of the schools. In Hong Kong, the secondary schools are classified into three bandings according to the academic performances of the primary students they enroll.

Table 4.2 Contents and approaches of the NOS teaching by the teachers

	NOS teaching approach	**Context**	**Target NOS aspects**	**Source of teaching plan**
CYT	Explicit, historical, integrated with content learning and experiment	Parallel developments of microscopes and the cell theory	Relationship between science and technology	Self-developed
NWY	Explicit, decontextualized NOS activities	Gestalt pictures, chest X-ray photos, mini-human in sperm, Martian human face, DCPIP colour change	Theory-laden observations; Science is made reliable through replication of experiments, accurate instruments and peer review	Researcher provided
LKY	Explicit, historical	The discovery of *Helicobacter pylori* as the main cause of peptic ulcers	science and technology; theory-laden observation; collective objectivity through critical peer review; science is evidence-based, but tentative; scientists are subjective and creative; theory and hypothesis	Researcher provided
PHF-1	Explicit, historical, integrated with content learning (immunity)	The discovery of smallpox vaccination by Jenner	Theory-laden observation; subjectivity of scientists	Self-developed

Table 4.2 Contents and approaches of the NOS teaching by the teachers (continued)

	NOS teaching approach	Context	Target NOS aspects	Source of teaching plan
PHF-2	Explicit, historical	Debates over the causes of dinosaur extinction	Science is tentative, evidence-based and limited; role of prediction; scientists are creative, subjective and theory laden, but collaborative; experiment is not the only way to do scientific investigations	Researcher provided
MPY-1	Explicit, decontextualized NOS activities	Reading illusions, chest X-ray photo, moon surface observation by Galileo, mini-human in sperm	Theory-laden observation	Self-developed
MPY-2	Explicit, NOS aspects infused into content learning (phototropism)	Historical experiments leading to the discovery of the mechanism of phototropism	Science is evidence-based; Science is tentative and evolutionary	Self-developed
WTY	Explicit, NOS aspects infused into content learning (Mendelian inheritance)	Mendel's hybridization experiments on peas that led to the discovery of the laws of inheritance	Scientific laws and theories	Researcher provided

Table 4.2 Contents and approaches of the NOS teaching by the teachers (continued)

	NOS teaching approach	**Context**	**Target NOS aspects**	**Source of teaching plan**
WYC	Explicit, historical	The discovery of the first antibiotics by Fleming	Scientists are theory-laden and subjective; scientific discovery needs luck; differences between science and technology; scientists are collaborating and competing; science is socioculturally embedded	Self-developed
KWM	Explicit, direct teaching of decontextualized NOS aspects, integrated with content learning (Kinetic theory)	Kinetic theory, but largely decontextualized	Science is creative; Science is evolutionary and revolutionary; Scientific theory is verified by making predictions	Self-developed

An in-depth analysis of the NOS teaching of individual participants were accomplished and included in the addenda. This section only presents an overview of the lessons of the participants, whereas detailed analysis of the teaching is left to the subsequent sections on the NOS aspects delivered in class, teaching approaches, communicative approaches and constructivist pedagogy.

CYT

CYT devised the teaching plan herself, making use of the history of the parallel developments of microscopes and cell theories to address explicitly the relationships between science and technology. The NOS aspects were infused into the scientific contents of the existing curriculum. Hence, this constitutes an explicit, integrated NOS teaching approach in the context of science history.

The storylines were crafted with rich contextual details and presented with many visuals. The teacher opted to depart from the commonly used *scientific language* (Lemke, 1990); instead, the classroom language was humorous, anthropomorphic, tentative, and instrumental, which not only added fun to the teaching process, but also portrayed a more informed nature of science to students. In addition, since the teacher took the integrated approach: NOS learning was embedded in the learning of subject matter, the NOS discussions were kept brief, which helped sustain the motivation and engagement of students.

The NOS aspects delivered in the class, however, was limited to a simple understanding that science and technology mutually affect each other in the context of the development of microscopes and the cell theory. The lesson did not address the more crucial NOS aspects about the differences between science and technology. The teacher oversimplified science as science disciplines, such as biology and astronomy, whereas technology was oversimplified as machines (CYT-T, 20–32). The extensive contributions of technology to modern human life were mostly overlooked and narrowed down to the mere role of microscopes to the discovery of cells (CYT-T, 91–97). On the other hand, the teacher did not seem to recognize the difference between *contextualized* and *decontextualized* NOS aspects. When the teacher asked, "What is the relationship between technology and science?" (CYT-T, 74), she never explained it beyond the case of microscopes and cells, nor did she explicitly tell students that these relationships are applicable to science in general, whereas the case of the microscopes and cells is just an example of such relationship.

Given the ample amount of questions from teachers and responses from students, the lesson appeared interactive. However, the communication did not involve many extended dialogues but predominately simple student talk. The teacher seldom asked the students to elaborate on their ideas, let alone challenged and worked with their ideas to construct the targeted NOS conceptions. In her self-reflection, she admitted not having sufficient confidence to engage students in open dialogues, making her employ a relatively authoritative way to keep the student responses in check.

NWY

NWY explicitly addressed the theory-laden nature of observations using a variety of interesting activities and examples: gestalt pictures, color changes of the DCPIP solution, chest X-ray photos, Martian human face, camouflaged insects, and miniature humans in sperms. These examples are either content-free or minimally related to science content.

However, the lesson could only touch on a simple understanding that observations are sometimes not objective and straightforward, without pointing out the role of theory-ladenness. The teacher explained to the students that Leeuwenhoek “saw” a miniature human in the sperm because of the limitations of microscopes, instead of attributing it to the *preformation theory* prevalent at the time. Similarly, the discovery of a “human face” in Mars was interpreted as an imagination based on the unclear photograph sent back from the Viking spacecraft, instead of the belief in the existence of Martians. In the eyes of the students, these cases were showing technological limitations rather than theory-laden observations. This kind of “observational inaccuracies” is easily avoidable with advances in technology, whereas the theory-ladenness of observations is inherently unavoidable.

The teacher did attempt to make generalizations of the NOS aspects illustrated by the activities to science in general. However, because the activities were only minimally related to authentic science, the generalized NOS aspects, if there was any, was likely limited to the activities rather than applicable to authentic science.

The teaching of NWY was interactive but not adequately dialogic. Although the teacher managed to solicit responses from students and ask students to elaborate on their ideas, the students predominately responded with a few words and extended dialogues were uncommon. The teacher appeared incapable of probing what the students were thinking about and working with their ideas through dialogues. In addition, she did not utilize the activities, such as the gestalt pictures, to create cognitive conflicts among students regarding their NOS understandings.

LKY

LKY used the lesson plan provided by the researcher to address a host of NOS aspects through the story of the discovery of *Helicobacter pylori* as the main cause of peptic ulcers. This is an authentic, contemporary scientific discovery that is not only legendary, but also rich in NOS aspects. Questions were raised alongside the story, guiding students to reflect on the NOS aspects embedded in the story.

Despite the richness and attractiveness of the story, the students were only moderately engaged in class as observed, especially towards the end of the 50-minute lesson. This was partly because the communication in class was relatively non-interactive and authoritative, involving lengthy teacher lecture and short dialogues that followed the pattern of IRE triads. Although there were instances in which students could talk in an elaborate manner, the teacher, however, failed to respond to students and to work with their ideas properly.

The teacher did not intentionally make generalizations of the NOS aspects embedded in the story to science in general. However, in the written evaluation after class, most students showed informed NOS understandings beyond the context and this may be attributed to the authenticity of the story.

In the self-reflection of the teacher, she expressed her worry and lack of confidence before the lesson: "I want to say more in class, but I do not know how to articulate so in detail." Her limited knowledge in both the story and NOS aspects probably constrained her from discoursing comfortably with the students, making her enact the lesson plan provided by the researcher in a scripted manner. Nevertheless, the outcomes of the lesson turned out to be far beyond her expectations, giving her strong confidence in NOS teaching in the future.

PHF

PHF made two attempts of NOS teaching in his 10^{th} grade classes: one making use of the story of how Jenner discovered the smallpox vaccine (Lesson One), and the other discussing the controversy over the causes of dinosaur extinction (Lesson Two). Both lessons utilized an explicit approach where the NOS aspects were discussed explicitly in class.

In Lesson One, the story on how Jenner discovered smallpox vaccines was developed by the teacher himself, which was embedded in the teaching of immunization. Hence, only a small proportion of class time was devoted to addressing NOS aspects through the story, whereas the majority of the time was used to teach the concepts of immunization.

To illustrate the differences between observations and inference, the teacher got the students entangled in a central question throughout the lesson: "After having cowpox, people would not get smallpox. Is this an observation or an inference?" (PHF-T-1, 1) This question seemed vague and ambiguous: Was it referring to the *causal claim* that having cowpox could prevent one from getting smallpox, or to *individual observations* that some milkmaids do not get smallpox after getting cowpox? The former is an inference, whereas the latter is an observation. Expectedly, the subsequent discussions around this question were confusing (PHF-T-1, 1–12). The teacher then tried to use a simpler example to illustrate this NOS aspect: interpreting mysterious dinosaur footprints. This example was interesting and simple; hence, the students were engaged in more active class discussions as observed. However, the teacher did not provide explicit bridging of this analogy of dinosaur footprints to the story of Jenner. Another NOS aspect addressed in Lesson One was the theory-laden subjectivity of other scientists who rejected Jenner's discovery. The teacher attributed this subjectivity partly to their lack of background knowledge needed to understand Jenner's work. However, some students, who already possessed knowledge of immunity, seemed to find it difficult to realize why the simple logic of vaccination was hardly understood by the scientists at the time. This is an inherent limitation of teaching the history of science to students; students cannot "think" like the people at the time, and they tend to appraise historical events from a modern perspective, particularly when the historical context is not explained properly.

In Lesson Two, the controversy over the causes of dinosaur extinction presented the students with an authentic, contemporary scientific issue. The scientific issue was not only rich in NOS aspects, but was also inherently engaging to students. Unexpectedly, even though the lesson plan was provided by the researcher, the students were not actively engaged in class as observed. This may partly be attributed to his communicative approach. Although the lesson was moderately interactive, the questions raised by the teacher were often vague, and the dialogues with students were authoritative. The teacher often asked "why" to probe into the ideas of students; paradoxically, he seldom responded to students' answers. He merely wanted to obtain the "intended" answers from the mouths of students prior to giving out his correct answers. Some of the students appeared tired of this kind of "extended" dialogues and opted out of the teaching. This is particularly true of Lesson B in which a whole 80 minutes had been devoted to NOS teaching.

In his interviews, he admitted that "the most difficult is to know what the students are thinking about" (PHF-I, 1:07). He expressed agreement with the NOS goals and recalled his research experience, but he seemed frustrated by the negative attitudes of students: "students asked is it really for exams?... If not, why you teach it?...When I explained [laws and theory], they asked why it took so long to explain it, go back to the normal topic [Mendel's laws]" (PHF-I, 53-55). In his interview,

MPY

MPY attempted to teach NOS in her 11th and 13th grade classes using two different approaches: an explicit, reflective approach that utilized decontextualized NOS activities in the 11th grade class, and a relatively less explicit approach that utilized experiments related to the mechanism of phototropism in the 13th grade class.

In the 11th grade class, the main NOS aspect addressed was the theory-laden nature of observations, which was illustrated through the game of reading illusions, the observation by Galileo that the moon was not perfectly smooth, the interpretation of a chest X-ray photo, and the observation of a miniature man in sperm by Leeuwenhoek. The lesson devoted most of the time to the game about reading illusions, which, however, was not science at all. Although other examples were slightly related to science, the examples were not properly utilized to illustrate the aspects of NOS. For instance, the teacher explained that scientists at the time of Galileo insisted that the moon was perfectly smooth because they were being influenced by the authoritative Aristotelian theory (MPY-T1, 247–248).

Another feature of MPY's lesson was that she spent much time talking about NOS aspects in a general, decontextualized manner, instead of explaining the NOS aspects grounded on concrete examples. This kind of generalized, abstract discussion on NOS aspects tended to be less engaging to students.

The teacher evaluated the learning outcomes with a survey at the end of the lesson: "Scientists may have different observations toward the same object as their observation may be affected by their knowledge. Raise your hand if you agree…” (MPY-T-1, 298). She was disappointed by the responses. Most of the students simply refused to raise their hands; in addition, among those who responded, most showed naïve, *objectivist* views. In her self-reflection and interview, she attributed the undesirable learning outcomes to the fact that students were simply overwhelmed by the NOS learning spending the entire 55-minute lesson, and they felt the lesson unrelated to their formal learning.

Suffering from the experience with the 10th grade class, MPY employed a content-integrated approach to teaching NOS in the 13th class: NOS aspects were *infused* into the subject content. First, the teacher taught a series of historical experiments related to phototropism (a part of the existing curriculum). Thereafter, she explicitly drew the attention of students to the NOS aspects embedded in the series of experiments: science is tentative, evolutionary, and cumulative. Both the teacher and the students appeared much more comfortable with this approach because it did not take away too much time from their “normal” content learning. Besides, this also made the act of learning about NOS aspects more condensed and focused. The students were more actively engaged in reflective, in-depth dialogues on the NOS aspects. In addition, the students were able to show rather sophisticated NOS views in the after-class written evaluation.

The lessons of MPY were highly interactive and moderately dialogic in light of the high frequencies of student responses and teacher questions in both lessons. As observed, she was competent in probing and working with the general ideas of students through dialogues. However, her ability in this respect appeared to be compromised when she taught NOS－something she was not familiar with and confident about. Consequently, she was only able to probe simple ideas from the students, but failed to have the students think and talk through their own ideas concerning the NOS aspects.

WTY

WTY is a young teacher holding a PhD in biology. In his 10^{th} grade class, he spent most of the time teaching about Mendelian inheritance, and then he used the last five minutes to discuss the scientific laws and theories. He explicated the conceptions of laws and theories as “Law and theory are at the same level. Law describes things, theory explains things. Law does not come from theory, whereas theory does not come from law” (WYT-T, 54). Apart from being oversimplified, the conceptions of scientific laws and theories put forward in class were also not connected with the examples used. The teacher mentioned Mendel’s “explanations” several times, but these “explanations” turned out to be “laws” rather than theories. The teacher did not explain why Mendel’s explanations are considered laws, but proceeded to cite the cell theory, along with Newton’s laws, in an attempt to render the conceptions more intelligible. However, he just mentioned the names of these examples but did not explain at all why the cell theory is a theory and why Newton’s laws are laws. Hence, his explication of scientific laws and theories was basically decontextualized from the Mendel’s laws and other examples he cited.

In SUSSI, WTY also showed his inaccurate understanding of laws and theories. He attributed the tentativeness of scientific theory to inaccurate technology rather than to the inherent problem of under-determination, and he agreed that theories are “uncovered” in nature and laws represent absolute truths (WTY-SUSSI). The teacher’s *absolutist* and *realist* NOS conceptions probably stemmed from his authentic research experience.

In the interview, WTY claimed that he taught other aspects of NOS in the lesson by describing the experiments of Mendel, although he did not draw them out explicitly. This is an implicit approach (Lederman, 2007, p.869). In addition, he appeared to conflate the processes of science with the nature of science (Akerson & Abd-El-Khalick, 2003).

The communication in the class was dominated by didactic talk interspersed with a few questions and student responses. Students were not significantly engaged throughout the class: responding passively, bending over the bench, and talking softly. Interestingly, in his self-reflection, the teacher claimed “the discussion atmosphere was good,” “there were a lot of dialogue,” and “most of them were involved in the questions I asked” (WTY-R).The teacher did not seem to be sensitive enough to student responses in class and did not have an awareness of his teaching style and approach.

WYC

The lesson of WYC employed an explicit, reflective approach that addressed a host of NOS aspects in the context of Fleming’s discovery of the first antibiotics and its subsequent mass production to save millions of lives during the Second World War. The lesson plan was self-developed and the storyline was carefully crafted with sufficient contextual details and rich NOS aspects. For instance, Fleming’s knowledge on vaccines and his experience as a military surgeon during the First World War made his discovery of penicillin more plausible. The outbreak of the Second World War also played a significant role in speeding up the mass production of penicillin. These contextual backgrounds illustrated that science discovery has its social and historical milieu. To prevent students from appraising the historical events from modern perspectives and in turn discounting their plausibility, the teacher kept on reminding students to think in the historical context: "Try to put you into the shoes of Lister" (WYC-T, 88).

WYC possessed a good grasp of NOS aspects, as exhibited by his self-developed lesson plan and what was explicated in class. He drew out the NOS aspects at the right moments of the story and framed the NOS aspects into appropriate questions to engage students in reflective discourses. The NOS conceptions delivered in class were elaborate, in-depth, and—more importantly—balanced. Many NOS aspects are dialectical and it is a great challenge to maintain a good balance of the dichotomies, for example, between the subjectivity and objectivity, and the durability and tentativeness of NOS. The exceptionally informed NOS conceptions of WYC probably resulted from the significant effort he exerted in preparing for the lesson, as he admitted in the interview.

WYC's explication on NOS aspects was mainly grounded on the story, but he also attempted to generalize these NOS aspects. Below is an example of his shift from a contextualized to a decontextualized explication of NOS aspects:

> T: He [Fleming] wanted to persuade other scientists. If he wants others to believe him, he must give some evidence to persuade them. When a scientist publishes his discovery, what challenge will he face? He will be challenged. But do you think this process of discussion is necessary in science? (WYC-T, 149)

The teaching was highly interactive and dialogic, dominated by questions from the teacher, elaborate student responses, and a significant number of self-initiated student questions. The teaching was also constructivist to a certain extent because the teacher sometimes challenged and worked with the ideas of students to jointly articulate the meaning of NOS aspects.

The teaching was not only met with active student responses, but also had good learning outcomes as evaluated through a written questionnaire. In the evaluation, nearly 90% of the students agreed that the lesson had made them reflect on and gained a new understanding of science. Particularly noteworthy were their rich and insightful views as revealed in their constructed responses, and some of their responses had even not been explicitly addressed by the teacher.

KWM

KWM is different from all other participants in the sense that he is an experienced physics teacher studying a master’s degree in education. He claimed he had long been interested in NOS and read many books about NOS. Hence, he decided to conduct a more systematic and extended attempt to teach NOS in his 10^{th} grade physics classes. NOS aspects were deliberately infused into the curriculum and explicitly addressed over a period of three months. However, he did not provide a detailed document on his lesson plans and his teaching practice during the period. Only one of the lessons was observed and audiotaped for analysis.

The observed class discussed the kinetic theory, in which the teacher spent approximately 14 minutes at the beginning of the class explicitly addressing some NOS aspects. He mostly talked about NOS aspects in a decontextualized, generalized manner. For instance, to show the revolutionary nature of science, he rightly cited Einstein’s theory of relativity, but made no attempt to explain why Einstein’s theory represents a paradigm shift from Newtonian mechanics. Instead, he spent a substantial amount of time discussing how he was amazed by the theory. In addition, his classroom talk was relatively didactic and non-interactive. Student engagement was also poor as observed.

After discussing with the researcher, the teacher decided to evaluate the learning outcomes with the Views on Science and Education (VOSE) questionnaire (Chen, 2006) in a pretest/posttest design against a control class. The results were not satisfactory. All but two NOS aspects—theory and law, and imagination in science—had *no significant differences* between the gains of the treatment and control classes.

As an experienced teacher, he insisted on emphasizing science content while addressing NOS aspects. However, he failed to integrate the content and the NOS aspects meaningfully and addressed the NOS aspects mostly in a decontextualized manner. Ironically, his enthusiasm for NOS made him too ambitious in addressing NOS aspect in class without attending to the needs of students.

Summary

The ten classes of the eight participants were examined in depth regarding how the participants taught NOS. All the classes explicitly addressed the NOS aspects, but in different contexts: historical case studies, content free NOS activities, science-based content, or a mix of these contexts. Some participants integrated NOS aspects with content learning, whereas some solely devoted the lessons to NOS learning. Lessons that utilized the history of science tended to be able to address richer aspects of NOS than the decontextualized NOS activities. However, the historical stories varied significantly in the richness of the plots and contextual details, which may have significant impacts on the learning outcomes. In that respect, the quality of the historical cases developed by the participants themselves (PHH-1, CYT) was generally unsatisfactory as compared to that provided by the researcher (LKY and PHF-2). Some may intuitively envisage that students would be more interested in the funny, content-free activities than the boring historical stories. Unexpectedly, the students' responses to the historical stories of science seemed to be even more positive than the content-free NOS activities, so long as the storylines were well crafted and vividly narrated.

There was no shortage of oversimplified, inaccurate, and erroneous NOS conceptions explicated by the teachers in class, particularly when the lessons were designed by the teachers themselves. Many of the participants did not intentionally generalize the contextualized NOS aspects to authentic science. Regular interchanges between contextualized and decontextualized NOS aspects (Ryder & Leach, 2008) was uncommon in the lessons. Some participants (KWM) significantly explicated the NOS aspects in a decontextualized manner.

Generally, the lessons of the participants were interactive but not adequately dialogic. A certain number of questions and answers were exchanged, but the ideas of students were not explored and worked with adequately. In addition, few teachers could have created cognitive conflicts and deep reflections among students regarding NOS aspects. Nevertheless, these findings are not unexpected given the inexperience of most of the teachers in dialogic teaching.

In the lessons with written evaluations, three obtained fruitful learning outcomes in terms of the NOS understanding of students (MPY-2, LKY, and WYC). These successful lessons are associated with a combination of factors: good lesson plans, more dialogic interaction, accurate explication of NOS aspects in an intelligent manner, and most importantly, active student engagement. These factors are to be discussed in the subsequent sections.

NOS UNDERSTANDING OF THE PARTICIPANTS

The NOS understanding of participants were assessed by the 2nd version of the Student Understanding of Science and Scientific Inquiry (SUSSI) questionnaire (Liang et al., 2006) (Appendix 2) both before and after they attended the NOS teaching course. The questionnaire assesses six major NOS areas: *observations and inferences, change in scientific theories, scientific laws and theories, social and cultural influences on science, imagination and creativity in scientific investigations, and methodology of scientific investigations*. Each area is assessed by four Likert-type items and one open-ended question. The results of the Likert-type items are shown in Table 4.3.

Most of the participants had marked improvements in their NOS understanding after the course, showing *informed* views in 4–5 out of 6 areas in the posttest. Therefore, the NOS teaching course was largely effective in improving their NOS understanding, with the exception of the "scientific laws and theories" area, which seemed most resistant to change. Nevertheless, the original NOS conceptions of the participants cannot be considered poor because very few of them held naïve views in the pretest. The constructed responses (included in the DVD ROM) generally corroborated the views revealed by the Likert-type items.

However, these "informed" NOS understandings, as assessed by the SUSSI, are called into doubt given the criticisms on quantitative NOS instruments (Lederman et al., 1998). This view is further corroborated by the analysis of the lessons of the participants. Many NOS aspects explicated in class were oversimplified, inaccurate, and even erroneous, despite the "informed" views of participants, as assessed by the SUSSI. In this study, the NOS understanding of a teacher is not solely determined by the quantitative instruments in an "out-of-classroom" context, as in many other studies, but

Table 4.3 Participants' NOS understanding as assessed by SUSSI (Liang et al., 2006) before and after the course

	Observations and inferences		Tentativeness		Scientific theories and laws		Social and cultural embeddedness		Creativity and imagination		Scientific methods	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
CYT	4.25(I)	4.75(I)	3.75(T)	4(I)	3(T)	3.25(T)	3.25(T)	4(T)	3.75(T)	4(I)	3.75(T)	4(I)
NWY	3.75(T)	4.5(I)	4(I)	4.75(I)	3.25(T)	2.75(T)	4(I)	4(I)	1.5(N)	4(I)	3.5(T)	3.75(T)
LKY	4(I)	4.5(I)	3.75(T)	4(I)	2(T)	4.25(I)	3.75(T)	4.5(I)	3.75(T)	4(I)	3(T)	4(T)
PHF	4 (T)	4.5 (I)	4.25(T)	4.75(I)	3.75 (T)	4.25(I)	3.25 (T)	4 (I)	3.5 (T)	4 (T)	4.5 (I)	5 (I)
MPY	4.25(I)	4.5(I)	3.75(T)	4(I)	2.75(T)	3.75(T)	4(T)	4.5(I)	3.5(T)	4.25(I)	3.75(T)	4.25(I)
WTY	3(T)	4(I)	4.25(I)	3.75(T)	3(T)	3(T)	3.75(T)	4(I)	2(N)	4(I)	4.25(I)	3.75(T)
WYC	4.5(I)	4.25(T)	5(I)	4.5(I)	3.5(T)	3.75(T)	3.5(T)	4.5(I)	4.25(I)	4.5(I)	4.5(I)	4.25(I)
KWM	3.75(T)	4(I)	4(I)	4.5(I)	3(T)	4(I)	4(I)	4(I)	3.5(T)	4.5(I)	4.5(I)	4.5(I)

Note: The figures are the average scores of the four Likert-type items for each area. Each item is given a score of 1-5: 4-5 are informed views,1-2 naïve views and 3 uncertain. The view of an area is classified as *Naïve (N)* if none of the four Likert responses receives a score > 3, and as *Informed (I)* if all four responses receive a score >3. Others are classified as *Transitional (T).*

is mainly determined by how the NOS aspects are explicated in actual lessons. Some may argue that how the NOS aspects are delivered in class is a kind of pedagogical content knowledge (PCK) (Schwartz & Lederman, 2002). However, the PCK of NOS aspects has subtle difference from NOS aspects themselves; PCK refers to the *pedagogical transformation* of the NOS aspects into effective activities and classroom talk (Geddis, 1993). Arguably, much of the inappropriate explication of NOS aspects in class has an obvious root in the NOS conceptions of teachers, as well as a problem of their pedagogical transformation. For instance, KWM wrongly used the transition of the atomic theory to the kinetic theory to exemplify the revolutionary nature of science, which likely stemmed from his inadequate understanding of scientific paradigms (as revealed in his interview), as well as an incorrect choice of example. Distinguishing between conceptual and pedagogical impediments to ineffective NOS teaching is imperative for the exploration of effective NOS teaching.

Therefore, in this study, the explication of NOS aspects in class by participants is viewed as a reflection of their NOS understanding as well as their PCK for NOS. In the lesson of WTY, he stated that “law and theory are at the same level. Law describes things, theory explains things. Law does not come from theory, whereas theory does not come from law” (WTY-T, 54). Although he accurately pointed out that laws and theories are not interchangeable and hierarchical, his explication falls short of being oversimplified and generally incomprehensible. Scientific laws are universal regularities of nature, whereas scientific theories are explanatory frameworks that can account for a wide range of natural phenomena. Laws and theories are both supported by extensive evidence; hence, they are durable, yet still subject to change. WTY seemed to lack these sophisticated views on scientific laws and theories, which forced him to give an oversimplified account of the NOS aspects in class. Moreover, his surface understanding of laws and theories also constrained him in illustrating the conceptions convincingly using the examples of Mendel's laws, Newton's laws, and cell theory.

In the lesson of MPY, she told students that "doctor A may say you have pneumonia, but doctor B may say you have no problem [given the same chest X-ray photo]" (MPY-T, 272) to illustrate the theory-laden nature of observations. This explication, however, is incomprehensible to students because their experiences tell them that medical doctors would not be so indecisive in their diagnosis. Even worse, it portrays a naive *relativist, constructivist* view of science to students. This teaching episode shows that teachers may easily convey a biased view to students when they do not understand the dialectic nature of the tentative/durable and subjective/objective aspects of science.

NWY taught about theory-laden observations with a variety of content-free NOS activities and examples. She successfully showed students that observations can sometimes be problematic and not objective, but she largely failed to show the role of *theory* in causing *flawed* observations. She explained the "human face" on Mars as a result of our *imagination* based on the *unclear* photo sent back from the space probe, rather than as a result of *beliefs* on the existence of Martians (NWY-T, 47–65). The "mini-human" in sperms was attributed to the *poor* quality of the microscope made by Leeuwenhoek, rather than to the *preformation theory* in his mind (NWY-T, 97–107). This kind of *inaccurate* observations, which are attributed to technological limitations, is by no means theory laden. She seemed to lack sufficient understanding of what *theory laden* means. However, she could still explicate rather accurate views of theory-laden observation in *general statements* during the lesson debriefing (NWY-T, 118). This clearly shows that NOS understanding in general statements do not guarantee contextualized understanding of NOS, which demands a much more in-depth mastery of

NOS conceptions.

PHF explained the differences between observations and inferences in the lesson as "observation is what you see…. Inference often involves subjective judgments… that implies observation often has no dispute" (PHF-T-1, 27). He appeared to hold the naïve view that observation is completely objective and distinct from subjective inference, forgetting the *theory-laden observations* he learned. Paradoxically, in the SUSSI, he agreed that "scientists' observations of the same event may be different" (Q1A). Again, this shows a discrepancy in the NOS understanding of teachers as assessed by NOS instruments and as explicated in class. Alternatively, it can be construed as a difference between NOS understandings in general statements and in contexts. To make the students even more confused, he asked, "After having cowpox, people would not get smallpox. Is this an observation or an inference?" (PHF-T-1, 1) Indeed, it is an inference when it refers to the *universal generalization* that having cowpox could prevent one from getting smallpox, but it is an observation when it is talking about *individual events* that some milkmaids do not get smallpox after having cowpox. The endeavor of science is all about *inferring* universal generalizations from particular observations. However, he seemed to lack that level of understanding. He told students that the answer to the question was an "inference". Expectedly, many students were puzzled and chose to withdraw from the class discussion.

As an attempt to address the relationships between science and technology, CYT said that science refers to science subjects, such as biology, whereas "technology is a kind of machine" (CYT-T, 20–31). She further illustrated the relationships with the example of microscopes and cell theory: the invention of microscopes supports the development of the cell theory, whereas the discovery of cells necessitates the further development of microscopes in return (CYT-T, 91–97). This explication is correct within the example; however, it has narrowed down the role of technology as meeting the needs of scientists, while neglecting its much wider role in meeting the needs of all humans in their everyday living. This has revealed the problem of the lack of generalization of the contextual NOS aspects to broader scope.

Only in the lessons of LKY, PHF-2, and WYC were the explicated NOS aspects largely accurate and in-depth. This may be attributed to the fact that their lessons were based primarily on the teaching resources provided by the researcher (except WYC), wherein the relevant NOS aspects were already elaborated in detail. The only exception was WYC, who developed the teaching plan on his own but was able to deliver rather accurate NOS aspects in class, which could be attributed to his dedicated preparation for the lesson.

As seen from the above analysis, the lessons of the participants were replete of oversimplified, inaccurate, and even erroneous NOS aspects. Some of these inaccuracies and errors were made in a decontextualized, general manner, but many more were made when the teachers attempted to explain the NOS aspects in particular contexts. This finding supports the notion that NOS conceptions are highly *context-bound* (Clough, 2005; Southerland, Johnston, Sowell, Settlage, 2005; Ryder & Leach, 2008). As such, when the participants learned about the NOS aspects in a mostly generalized manner or within limited contexts in their teacher education courses, they were faced with a great challenge in transferring their NOS understanding to the novel contexts of their own lessons. This view is corroborated by some studies in NOS literature (Abd-El-Khalick et al., 1998; Akerson & Abd-El-Khalick, 2003; Lederman, 1999). The extent of the transfer barrier is likely dependent on the discrepancy between the contexts that teachers learn about NOS and NOS teaching, and the contexts in which they teach NOS in the actual classrooms. In this study, the lessons utilizing the teaching resources provided in the NOS teaching course (LKY and PHF-2) generally addressed more accurate NOS aspects than the lessons planned by the participants themselves (CYT, PHF-1, MPY-1, and KWM). LKY even admitted that she just read the teaching materials briefly a day before the lesson without much preparation, but surprisingly, the outcomes were good. The only exception was WYC who developed his own teaching plan but was still able to deliver NOS aspects quite accurately. To do this, he invested substantial effort in researching about the history of Fleming's discovery of antibiotics, as well as identifying the NOS aspects in the discovery. He was the only participant who had sent the lesson plan and teaching materials to the researcher for opinions. His devotion in the preparation of the lesson allowed him to overcome the transfer barriers successfully. However, participants who developed their own lesson plans without putting in sufficient effort generally obtained unsatisfactory outcomes.

In summary, the NOS understanding of the participants were found to be satisfactory in terms of the results of the SUSSI, but such results were deemed invalid in terms of the NOS aspects they delivered in class. The discrepancy suggests that NOS understanding is mostly context bound. Hence, the participants failed to transfer their generalized NOS understandings acquired from the NOS teaching course and shown in the NOS instrument to the specific contexts of their own teaching. This transfer problem constitutes the conceptual impediment to effective NOS teaching, as well as the pedagogical transformation of the understanding into classroom activities and discussions. Without an in-depth understanding of NOS aspects related to the context or content of lessons, the NOS conceptions can hardly be delivered in ways that are intelligible and plausible to students. The distance of transfer can be narrowed by providing teachers with quality teaching resources. Nevertheless, the transfer problems can be overcome by the teachers themselves, as shown by WYC, if they invest sufficient effort in understanding NOS aspects grounded on the specific contexts of their lessons.

APPROACHES TO NOS TEACHING

The most widely known and researched approaches to NOS teaching are the *explicit* and *implicit* approaches. The explicit approach has been widely proven by empirical research to be more effective than the implicit approach (Abd-El-Khalick & Lederman, 2000a, p. 692; Lederman, 2004, 2007). However, as argued in Chapter Two, this explicit/implicit dichotomy falls short of being not sufficiently specific to depict NOS teaching. In this regard, a new framework is proposed to characterize the NOS teaching approach of the participants, based on the literature review and the findings of this study (see Table 4.4).

Table 4.4 Framework for the characterization of approaches to NOS teaching

Dimension A: Explicitness/reflectiveness of NOS teaching

low ⟶ high

No explicit talk on the NOS aspects	Explicit talk on *decontextualized* NOS aspects	Explicit talk on *contextualized* NOS aspects	Engagement of students in *reflection* of the NOS aspects

Dimension B: Context of NOS teaching

Unauthentic science ⟶ authentic science

Decontextualized NOS activities	Scientific inquiry activities	Science concepts	Science history and socioscientific issues

This framework characterizes NOS teaching approaches in two dimensions, namely, *explicitness/reflectiveness* and *context*. In the explicitness/reflectiveness dimension, the left end denotes the implicit approach where no NOS aspects are explicitly brought to the attention of students. This approach is identified when teachers state the NOS goals in lesson plans or in interviews but no explicit address of the target NOS aspects is found in class. Explicit talk on NOS aspects is refined into three levels, namely, talk on *decontextualized* NOS aspects, talk on *contextualized* NOS aspects, and talk engaging students in *reflection* on NOS aspects. This delineation of explicit NOS talk is necessary because the different levels of NOS talk differ in effectiveness in producing conceptual changes in NOS conceptions among students. The lowest level of explicit NOS talk is where the teacher addresses the NOS aspects in a decontextualized manner with general NOS statements, such as "science is tentative," which are likely to be unintelligible and unconvincing to students. The conceptions of students are likely to change when the NOS aspects are convincingly illustrated by specific contexts. The highest level of explicit NOS talk is where the teacher engages students in thinking about NOS aspects reflectively or places them in cognitive conflicts, which are deemed powerful means for conceptual change (Clough, 2006; Lederman, 2006; Ryder & Leach, 2008). "Reflection of the NOS aspects" means that students are guided to think about their own ideas toward science through extensive dialogues. The different levels of talk are not mutually exclusive, with the higher levels subsuming the lower levels. The right end of the explicitness/reflectiveness dimension represents what the literature commonly calls the *explicit, reflective* approach. Usually a lesson consists of a mix of different levels of talk in varying amounts. Hence, judgments have to be made on the quantity of the different kinds of talk to determine the principal approach, if any, of the NOS teaching.

The *context* dimension draws on the *decontextualized/contextualized* continuum developed by Clough (2006) (see Table 2.2). According to this framework, the authenticity of the context with science is significant because students will exit NOS lessons without real conceptual change in their views toward science if they doubt the authenticity of the contexts. The most effective approach to NOS teaching is in the context of authentic science, although Clough (2006) suggested the use of decontextualized activities, such as scaffolding. On the left end are decontextualized NOS activities, such as gestalt pictures and black box activities, which are content-free and unauthentic science. The minimally science-related activities, such as the dinosaur footprints inquiry, can also be placed in this category. Scientific investigations at school are only considered as moderately authentic science because they differ greatly from authentic science (Chinn & Malhotra, 2002). Some science concepts are associated with NOS aspects, such as the cell membrane models and Mendel's laws of inheritance, which are certainly authentic science. However, they are still not as authentic as science history and socioscientific issues that involve rich NOS aspects in the social and historical contexts. Nonetheless, the authenticity of these contexts with science depends on how the contexts are constructed. An extended, open scientific inquiry could be more authentic than a highly simplified historical case study of science.

With this framework, the NOS teaching approaches of the participants were analyzed and the results are shown in Table 4.5. The lesson of PHF-1 is used to illustrate how the analysis was made. The lesson of PHF-1 consisted of two contexts: Jenner's discovery of smallpox vaccine and dinosaur footprints, so his lesson appeared in two columns of the contexts: decontextualized NOS activities and history of science. In the explicitness/reflectiveness dimension, a mix of different kinds of talk is usually present in a lesson. The relative proportions of different kinds of talk in a context are represented by one to five "+" symbols in brackets. For instance, in the lesson of PHF-1, when the teacher was talking about dinosaur footprints, the classroom talk was mostly contextualized talk (+++) with some reflections (++). The numbers of pluses only show the *relative proportion* of different kinds of talk made by a teacher in a context, but do not represent the actual amounts of talk that can be compared across contexts and classes. The assignment of "+" is by no means quantitative, but somehow interpretive. Its reliability is enhanced by another science educator who did the coding independently and disagreements were resolved through discussions.

Table 4.5. Approaches to NOS teaching by the teachers

	Context			
Explicitness/ reflectiveness	Decontextualized NOS activities	Scientific inquiry activities	Science concepts	Science history and socioscientific issues
No explicit attention to the NOS aspects			WTY (++)	PHF-1(+)
Explicit talk on decontextualized NOS aspects	MPY-1(++) NWY(+)		MPY-2(++) KWM (++++) WTY(++)	PHF-1(+) CYT (++), WYC(+)
Explicit talk on contextualized NOS aspects	PHF-1(+++), MPY-1(++) NWY (+++)		MPY-2(++) KWM (+) WTY (+)	PHF-1(++), PHF-2 (+++), CYT(++), LKY(++++), WYC(++)
Engagement of students in reflection of the NOS aspects	PHF-1(++), MPY-1(+) NWY (+)		MPY-2(+)	PHF-1(+), PHF-2(++), CYT(+), LKY(+), WYC(++)

Note: The relative amounts of different kinds of talk of a lesson are represented by one to five "+" symbols in brackets.

Contexts

In the study, the contexts for NOS teaching were predominantly based on the history of science, whereas none was based on scientific inquiry and SSIs. As revealed from their self-reflections and interviews, most of the participants found it challenging to teach NOS while conducting science investigations. First, the participants were used to recipe-type experiments and were unfamiliar with open investigations. They seldom engaged students in pre-lab and post-lab discussions on experimental designs and data analysis, where rich NOS aspects can be derived. To make it more challenging, the NOS aspects grounded in such discussions are patently emergent, and they cannot be planned in advance, which require teachers to have a good grasp of NOS aspects. As such, although some examples of NOS teaching utilizing scientific investigations were introduced in the NOS teaching course, none of the teachers tried this approach in their own classes. As for the SSIs, the participants mostly considered the topic irrelevant to the curricula that they were teaching, and they also considered the scientific content involved too difficult for students.

In the contexts of science history, the lessons were generally found to have richer, more reflective NOS discussions than the lessons that made use of science concepts and decontextualized NOS activities. This may be attributed to the fact that the NOS aspects embedded in science history are much richer than those in science concepts and NOS activities, particularly for the humanistic and social aspects of science. However, the success of lessons that utilize science history depends heavily on the quality of the historical story in illustrating the target NOS aspects. Both CYT and PHF-1 utilized short stories of scientific discovery developed on their own, whereas LKY, PHF-2, and WYC engaged students in storylines around certain themes, including the bacterial cause of ulcers, the cause of dinosaur extinction, and the discovery of penicillin. The long stories tend to show more diverse and in-depth aspects of NOS than the short stories due to their rich contextual background. However, given that two out of the three long stories were provided by the researcher (LKY and PHF-2), the availability of this kind of long stories is probably the main reason limiting their usage. When the stories were developed by the participants themselves (CYT and PHF-1), the stories were generally simple and short, lacking adequate contextual background to allow students to appreciate the NOS aspects and think from historical perspectives. In the lesson of CYT, she virtually did not mention any scientific or social background in the 16^{th} to 18^{th} centuries that was relevant to the development of microscopes and cell theories. The lesson of PHF-1 is better in the sense that he provided more historical background for Jenner's discovery of smallpox vaccines, but the evolution of scientific ideas on immunity, germs and medicines was still not sufficiently explained. By contrast, in the case of the discovery of the bacterial cause of ulcers (LKY) developed by the researcher, the complex socioeconomic factors that contributed to the resistance of the gastroenterologists against the new theory were provided, such as that many of them relied on endoscopy examination as their main income, and that some were associated with the companies that produced antacids. These social backgrounds, coupled with the explanation of the traditional acid theory of ulcers, made the initial rejection of the bacterial theory of ulcers highly intelligible and plausible. The story in such richness was also engaging to the students. However, all the participants had expressed that they did not have the knowledge and time to develop this type of historical case to teach NOS. Even when teaching materials were provided, they also found the history of science overwhelmingly difficult for them:

> The content [story of H. pylori and ulcers] is already very difficult to me. I have to remember them all in teaching, and even need to identify the NOS…Luckily you gave me the materials … but I think I can only talk about them fairly … I have no time to think more about it (LKY-I)

For the lessons addressing NOS aspects through science concepts, the emphasis of the lesson would easily be skewed toward the concepts rather than the NOS aspects. Usually, only a small proportion of class time is devoted to NOS, and the aspects of NOS addressed are often simple. In the following self-reflection of a teacher (MPY), the precedence of science contents over NOS was clearly shown:

> I found that the learning outcome from approach 1 [teaching NOS with the whole lesson] is not satisfactory. The main reason is that students are not ready to receive too intensive NOS knowledge.… As the HKCEE syllabus is so tight, I can only afford one or two classes to teach specially for NOS…
>
> Learning outcome from approach 3 [normal teaching infused with a few sentences about NOS] is satisfactory. This approach is the most natural and time saving one. It will be excellent if teachers can *use this approach continuously* during teaching. Students are *unconsciously* received the concept on NOS.…However, the difficulty I deal with in using this teaching approach is that I do not have enough experiences and "sense" to discover and deliver NOS concepts in different topics. (MPY-R)

The views revealed by the above excerpts likely represent that of most teachers: a tiny bit of NOS infused into science contents is a more realistic and sustainable goal for NOS teaching. However, one idea in the excerpt is noteworthy: "*unconsciously* received the concept on NOS", which implies an implicit approach to NOS teaching.

However, treating NOS aspects briefly in conjunction with concept learning is probably ineffective. The effectiveness depends on how to integrate science concepts with NOS aspects seamlessly: NOS aspects are illustrated by science concepts, and the discussions of NOS aspects facilitate the understanding of science concepts. The lesson of MPY-2 was effective given active student responses and the results of the evaluation. In contrast, the lessons of KWM and WTY have failed. The main difference is that MPY could engage students in in-depth reflection of the NOS aspects grounded on the science concepts just taught, whereas KWM and WTY did not associate the NOS aspects with the science concepts and explained them largely in a decontextualized manner. KWM and WTY appeared to assume that students would make the connection automatically.

Some lessons utilized decontextualized, content-free NOS activities, such as gestalt switches and reading illusions, in teaching NOS (MPY-1, NWY). Some of these activities are modified to make them moderately related to science, such as mini-humans in sperms, the chest X-ray, and the Martian human face. They are advocated by some science educators as "classroom-tested activities for the successful teaching of NOS" (Lederman & Abd-El-Khalick, 1998, p. 313). The availability of these activities (e.g., Bell, 2008; Lederman & Abd-El-Khalick, 1998; Warren, 2001) make them widely used in classroom NOS teaching. However, the effectiveness of these activities in promoting conceptual change in NOS conceptions among students is called into doubt because of their being unauthentic science (Clough, 2006). As revealed from the lessons of MPY-1 and NWY, at best, these activities promote limited and localized understanding of NOS. For instance, the gestalt switch and reading illusion used in the lessons can show students that observations may be obscure in some "tricky" occasions, but it is unconvincing that theory-ladenness underlies most of our observations, let alone affect accurate observations by scientists using sophisticated instruments. Moderately contextualized NOS activities, such as the mini-humans in sperms observed by Leeuwenhoek, are better in their authenticity. But their effectiveness is discounted when they are used in an ahistorical manner. For example, the "mini-humans in sperms" only have significance in the historical context of the theories of *epigenesis* and *preformation* regarding how life originates (Magner, 2002). However, both NWY and MPY-1 did not mention the historical conceptual background at all, thus making the case no better than decontextualized NOS activities in terms of NOS learning. Nonetheless, these content free activities are engaging, and they can be used as scaffolding for NOS learning in highly contextualized historical contexts (Clough, 2006). In the lesson of PHY-1, he used the mystery dinosaur footprints as a scaffold to understand the theory-laden subjectivity of scientists who rejected Jenner's work. However, the effect of scaffolding was not obvious because the teacher did not explicitly bridge the analogy (dinosaur footprints) to the context of authentic science.

Explicitness/reflectiveness

As shown in Table 4.5, the participants mostly employed an *explicit* approach in their NOS teaching—the NOS aspects were brought to the attention of the students explicitly. This is because they learned from the NOS teaching course that only in such way will NOS teaching be effective. In the lessons of WTY and PHF-1, some of the NOS aspects were taught implicitly because these NOS aspects were not explicitly taught but they claimed they had addressed them in class.

Too much decontextualized NOS talk is detrimental, as seen in the lessons of KWM and WTY and MPY. This kind of NOS talk produces very limited NOS understanding as it tends to be unintelligible and simple. Moreover, the motivation of students is easily destroyed by its abstractness. However, when used briefly to probe the ideas of students at the beginning of the class, decontextualized NOS talk can be constructive, as exemplified in the lessons of CYT and WYC. This notion is corroborated by the study of Schwartz and Lederman (2002), which found that students are mostly unresponsive when teachers attempt to discuss some general NOS questions, such as "Why is science subjective?" (p. 225). The excerpt below shows how KWM attempted to explain that scientific theories are provisional and subject to change. He did draw on some examples such as the atomic theory, but the explication was largely decontextualized and unintelligible. Another problem with this excerpt is that it lacked a clear focus, shifting suddenly from the provisional nature of scientific theories to the testing of theories. The lesson of KWM was replete of this kind of talk and the students appeared not adequately engaged by the talk.

> So, science is a matter of facing the phenomenon, making observation, collecting and analyzing data, trying to prove the theory. Must the theory be right? Not really. It is possible that theories are proved to be wrong as science develops. For example, atomic theory has been discovered and believed for 2000 years until the kinetic theory. …Then, how can we prove that Albert Einstein's theory is right? In what ways do you think we can prove this theory? What should we do? What should we do to check whether a theory is right or wrong? …Any method to check? (KWM-T, 46)

Ironically, some teachers (e.g., KWM and MPY) appeared to be too enthusiastic in discussing the NOS aspects with students that they unintentionally talk too much in a decontextualized manner. Another finding is that lessons integrating NOS learning with concepts tend to involve higher proportions of decontextualized talk (KWM, MPY-2, WTY).

Contextualized NOS talk is at the heart of effective NOS teaching. In most of the lessons, particularly those in the contexts of science history, the NOS aspects were largely addressed in contexts. A contextualized NOS talk can involve generalized NOS aspects as Clough (2006) suggests. The following excerpts from the lessons of PHF-2 and NWY illustrate this kind of interchange between contextualized and generalized NOS talk.

> As you can see [the debates over the cause of dinosaur extinction], scientists may not be as objective as we think. (PHF-T-2, 91)

> What will affect our observation when we are doing science? The first is our personal experience, just like the game we played [the gestalt switch]; the second one is our knowledge, just like the X-ray photo, if we've never seen the X-ray photo before, then you won't be able to know what it is. The other is subjectivity: affected by your experience and thinking. It seems that science is not very reliable and objective, but how come there are still many people believe in science? (NWY-T, 118)

The generalization of contextualized NOS aspects is considered a necessary condition for effective NOS learning. First, and the most important one, it fosters the understanding applicable to science in general rather than to the specific contexts only. Second, the NOS aspects are made more plausible and fruitful to students when they learn that these aspects are applicable to science in general as well as the contexts. Third, generalizations let students reflect on the NOS aspects rather than the contexts. However, regular interchanges of contextualized and generalized NOS aspects were not a common feature in most of the lessons of this study.

Engaging students in reflective discourses on NOS aspects is probably the most difficult for teachers. In most lessons of this study, students were scarcely engaged in reflections on NOS aspects. The participants generally lacked the skills to work with students' ideas, particularly when NOS aspects were being discussed. Some teachers did the reflections for their students through didactic talk. The following excerpt is a case in point, in which the teacher attempted to explain how theory-laden observations prevented scientists from accepting the Marshall's bacterial theory of ulcers.

> Many scientists, especially gastrointestinal scientists, believed that hyperacidity is the main cause of gastric ulcer, and it is not related to bacteria. And they didn't believe that bacteria can survive in such an acidic environment. They only relied on the knowledge they have. The knowledge was deep in their brain. If there is gastric ulcer, they would think that it is because of hyperacidity and would not think that it is caused by bacteria. (LKY-T, 36)

The above talk is didactic; the ideas of students were not made visible and worked on at all. Instead, the same meanings of the episode could be brought out through dialogues with students with questions like: Why did gastrointestinal scientists hold on to their ideas despite the findings of Marshall? Shouldn't scientists be objective? This kind of reflective exchanges is supposed to be much more powerful than the didactic talk in producing conceptual change on the NOS conceptions of students. Unfortunately, this was scarcely found in the lessons of the participants. Below are two uncommon exchanges that can illustrate what "reflective discourse" means.

> T: After Lister has done the sterilization [applying carbonic acid on wounds], the death rate due to infections has decreased greatly, from 45% to 10%…. If there is no Pasteur [discover germs in air], would there still be Lister? Would there still be Lister's discovery [sterilization method] ?
>
> S: He [Lister] didn't know it is bacteria.
>
> T: He didn't know it is bacteria.
>
> S: If he didn't know the disease is caused by bacteria in the air, he will not know using sterilizer to kill the bacteria.
>
> T: Right. If he didn't know there are bacteria in air which cause illness, he will not do this kind of thing [invent sterilization method]. So, you can see, can science develop with one step? You can see from this example… Probably no. You can see it. (WYC-T, 39–43)

> T: Heated debate aroused among scientists [over the cause of dinosaur extinction]. Some selectively used their data - neglected the data unfavourable to them or used very stringent standards to criticize their opponents. Why? They are scientists and should be objective?
>
> S: They have to support their arguments…
>
> T: Why? They are scientists and should be objective.
>
> S: They need funding

T: That is possible.

S: They are not certain [about the cause of dinosaur extinction]. If it is certain, there is no need to argue.

S: They want to get the Nobel Prize.

T: As you can see, scientists may not be as objective as we think. …To support their views, they will only look at the supporting data, while the contradictory ones will be slightly mentioned. (PHF-T2, 88–91)

In conclusion, the lessons observed showed that NOS teaching in the context of science history is probably more effective, in terms of student engagement and the intelligibility and plausibility of NOS aspects, than that through science concepts and decontextualized NOS activities alone. The historical stories of science developed by the participants, however, were not adequately rich in its contextual background to make NOS aspects intelligible and plausible to students. To use science concepts to address NOS aspects, the science concepts and the NOS aspects have to be seamlessly merged: the NOS aspects are convincingly illustrated by the science concepts, and the NOS discussions help with the understanding of the science concepts. When used properly, scientific content is likely the means of NOS teaching that is least resisted by teachers and students. Decontextualized NOS activities are better used in conjunction with other contexts to serve as analogies or scaffolds for authentic science, but explicit bridging is needed. No matter what contexts/activities are used, the explicit teaching of NOS is best to be grounded in contexts rather than with decontextualized talk. An interchange between contextualized talk and generalized talk on the NOS aspects is desirable, but were scarcely found in the lessons observed. The mostly needed aspect of effective NOS teaching is probably reflective dialogues with students. Most participants, however, did not show competence in that respect.

ANALYSIS OF CLASSROOM TALK AND COMMUNICATIVE APPROACHES

One important component of effective NOS teaching is the communicative approach that teachers use in addressing NOS aspects. A framework of analysis was drawn heavily on the framework initially developed by Mortimer and Scott (2003, p. 25) and subsequently improved by Ryder and Leach (2008), in which classroom talk is conceptualized in two dimensions: *interactive/non-interactive, and authoritative/dialogic*, producing a total of four communicative approaches: *interactive/authoritative, interactive/dialogic, non-interactive/authoritative, and non-interactive/dialogic.* Interactive communication refers to the degree by which students are allowed to talk in the classroom, whereas dialogic communication refers to the degree by which students' ideas are heard, respected, and worked with in the classroom (Mortimer and Scott, 2003, p. 34). These approaches are actualized through patterns of discourses, such as the initiation-response-evaluation (IRE) triads and the initiation-response-feedback-response-feedback (IRFRF…) exchange. A particular communicative approach, however, is not by nature superior to another, depending on the teaching purposes of the talk and the nature of the knowledge to be delivered. For instance, when a talk is aimed at exploring students' views, an interactive/dialogic approach is the most appropriate. However, when the aim is to work with students' ideas in order to introduce a concept, an interactive/authoritative approach is more effective, so is the non-interactive/authoritative approach for introducing science concepts.

Different from science concepts, NOS conceptions are by nature philosophical.

This nature of NOS conceptions, together with the naïve NOS conceptions widely held by students (Lederman, 2007, p. 869), requires effective NOS teaching to be mostly interactive, dialogic, and reflective, in which students' ideas are explored, challenged, and worked on for possible conceptual changes. Hence, using the appropriate communicative approaches is at the heart of effective NOS teaching.

To provide a basis for the analysis of communicative approaches, teacher and student talk in the teaching transcripts was coded and counted according to the framework described in Chapter 3, and the results are presented in Table 4.6. Take for example, in the lesson of CYT, the teacher spent 22.5% of time in addressing the NOS aspects directly, in which students made 23 talks in response to the teachers and asked 7 questions, whereas the teacher posed 28 questions and conducted a class survey. The validity of the coding of the classroom talk was enhanced by another science educator who did the coding independently from the researcher. Any discrepancies were resolved through discussions. For instance, the *metacognitiv*e talk and *reflective talk* were a bit confused initially and were later distinguished more clearly.

As seen from Table 4.6, the class time spent on explicitly addressing the NOS aspects varied considerably across the participants, which depended very much on whether the lessons aimed at science concepts, as well as NOS aspects. The lessons integrated with content learning, such as the lessons of WYT, PHF-1, WTY, MPY-2, and KWM, often had much lower proportions of class time devoted to NOS discussions. PHF-2 used the whole lesson for NOS teaching, but a substantial amount of the class time was spent on explaining the contextual details and the science concepts of the story, leaving only half of the lesson time to address the NOS aspects directly. As seen from this, teachers may lose sight of the goal of NOS teaching but placing emphasis on the contextual information or the activities.

Table 4.6 Types and numbers of talks in the lessons when addressing NOS aspects explicitly

	CYT	NWY	LKY	PHF-1	PHF-2	MPY-1	MPY-2	WTY	WYC	KWM
% of class time addressing NOS aspects explicitly	22.5% of 80 min	90% of 40 min	80% of 45 min	20% of 70 min	54% of 70 min	90% of 55 min	27% of 55 min	15% of 35 min	72% of 80 min	29% of 45 min
Student talk										
Total talk	23	53	34	20	34	83	29	3	77	8
- Simple	21	48	22	18	32	72	24	3	59	5
- elaborate	2	5	12	2	2	11	5		18	3
Frequency of talk (no./min)	1.28	1.33	0.94	1.43	0.94	1.66	1.93	0.57	1.35	0.57
Self-initiated talk		1	3		11	8	4		8	
Group talk			1			1			1	
Ask questions	7	1	1	3	3	2				
Talk responding to classmates									1	

Table 4.6 Types and numbers of talks in the lessons when addressing NOS aspects explicitly (continued)

	CYT	**NWY**	**LKY**	**PHF-1**	**PHF-2**	**MPY-1**	**MPY-2**	**WTY**	**WYC**	**KWM**
Teacher talk										
Total questions	28	58	32	15	33	69	28	3	76	8
- closed	3	3	2	2	0	4			4	
- open	10	24	2	3	3	30			12	1
- elaboration	5	8	12	4	9	17	9		20	4
- reflective	5	21	14	3	15	13	12	3	31	1
-metacognitive	5	2	2	3	6	5	7		9	2
Frequency of questions (no./min)	1.56	1.45	0.89	1.07	0.87	1.38	1.87	0.57	1.33	0.57
Class survey	1		1	1	1	5			1	
Generalization		5			2	6	3	1	5	1
Illustration		6				3	2	2		2
Significance of NOS learning		1				1				1

Note: The numbers show the times of talk made by one person without interruption. The kinds of the talk have been defined in Chapter Three.

The interactivity of the lesson can be revealed from the frequencies of student talk and teacher questioning, as well as the number of small group discussions and class survey conducted in class. As such, most of the lessons are deemed interactive, although at varying degrees, except that of WTY and KWM. The lesson of WTY was dominated by content learning, whereas that of KWM by didactic teacher talk, both involving very few teacher-student interactions.

As for the dialogic/authoritative dimension, evidence was sought on the extent to which students' ideas were made open, developed, and worked with in class. Data that can shed light on this aspect include elaborate student responses, student-initiated talk and questions, student responses to their classmates, and teacher questions that are open, elaborative, and reflective (Table 4.6). These data, however, have to be complemented and corroborated by the analysis of the teaching transcripts. Below is an exchange exemplifying dialogic communication in WYC's lesson, in which he attempted to probe and work with students' ideas on what science is at the beginning of the class. It was an extended dialogue between students and teacher, in which the teacher sophistically guided the students to elaborate and clarify their ideas, and monitored the direction of discussion.

T: Let me ask you. Does anyone want to express your feeling toward scientists or the difference between scientists and normal people? Anyone? We will later… [Probe students' ideas with an open question]

S: They have made some special contributions to the society.

T: Some special contributions. Could you give some examples? [Ask for elaboration]

S: Create a new realm for the society.

T: Create a new realm. Could you say more about what the realm relates to? [Ask for elaboration]

S: A factor towards our living.

T: It may bring changes to our living and better our standard of living. [Recast the student's idea and made it public] Anyone else? May be I can give some more directions to think about. Which characteristics do you expect a scientist to possess that makes them superior than a normal person? We will require these characteristics more of a scientist than a normal person. If one doesn't have them, one will not be a scientist. [Focus the direction of discussion through elaborating and rephrasing the questions]

S: The ability to observe and analyze should be higher.

T: The ability to observe and analyze should be higher. Why? [Ask for elaboration]

S1: Because they have to observe and analyze things.

T: Because they have to observe and analyze things. OK... Let's see if it is true. Anyone else? [Probe more student ideas]

S: They should have great vision.

T: What is the meaning of great vision? [Ask for elaboration]

S: To think about what should be invented for the future.

T: Invent things by considering the future's need.[Recast the student idea and make it public] OK, to have great vision. Let's see if others have the same view. Ask one more student and then we will start today's lesson. [Probe more student ideas]

S: To develop new knowledge through studying things carefully.

T: Through studying things carefully? [A confirmatory exchange]

S: Study things of the environment carefully. Something material.

T: What do you mean about studying things carefully? [Ask for clarification]

S: For example, enzyme. You don't know what is growing at first, but you will prove the rule behind through careful observation.

T: Ok. Just like what this student has said, scientists need to have high ability to observe… [Capitalize on student ideas to give a joint conclusion] (WYC-T, 4–25)

The following exchange shows a less dialogic communication, in which the teacher attempted to probe and work with students' ideas on the differences between science and technology. Different from those of WYC above, students' ideas were solicited but not elaborated and worked on adequately. The responses of the students were simple, and the dialogues, if any, were often ended prematurely with an authoritative conclusion made by the teacher. This kind of interactive but authoritative communication was found prevalent in many of the lessons of the participants.

T: Is this scientific discovery or technological invention? [The breathing test for the bacteria H. pylori in stomach]

S1: Both.

T: Both.[Confirmatory exchange]

S2: It's discovery. How can it be an invention?

T: Discovery or invention? [Repeat the question but does not ask for elaboration]

S2: Discovery.

T: Invention. Raise your hand if you think that it is invention. You are afraid to raise your hand or what? …[Ignore student's response and conduct a class survey]

T: It is technological invention. It is mainly because…[Give out the answer authoritatively] (LKY-T, 66–73)

WTY showed the most non-interactive/authoritative communication among all the participants. In the exchange below, after spending almost the whole class on teaching about Mendelian inheritance, he attempted to introduce NOS aspects about scientific laws and theories. He did ask questions, but the questions were used to elicit "intended" answers out of the mouth of students rather than to know what the students were thinking about. Similar to the case of LKY, students' ideas in this exchange were not made public and worked on significantly, but were instead dominated by the teacher's thinking.

T: The last question for you to think about is: How are laws different from theories? Which one is more powerful? [Ask two open questions at one time to probe students' ideas]

S: Laws

T: Laws? So physics is more powerful than biology? What is the meaning of laws and theory? Newton's law F=ma. It is used for what? [Give out clues. Multiple questions are asked at one time and the messages are confusing]

S: Calculation

T: Beside this? You think about it. It only give out a description – the relationship between F, m and a. Does it explain why? [Do not respond to student's answer directly and keep on clueing the students]

S: No

T: No… what about theory, like cell theory. Is it so simple to describe things? All organisms are made of cells …Law and theory are at the same level. Laws are describing thing, theory explain things. Law does not come from theory while theory does not come from laws [Give out the answer authoritatively]

(WTY-T, 1–7)

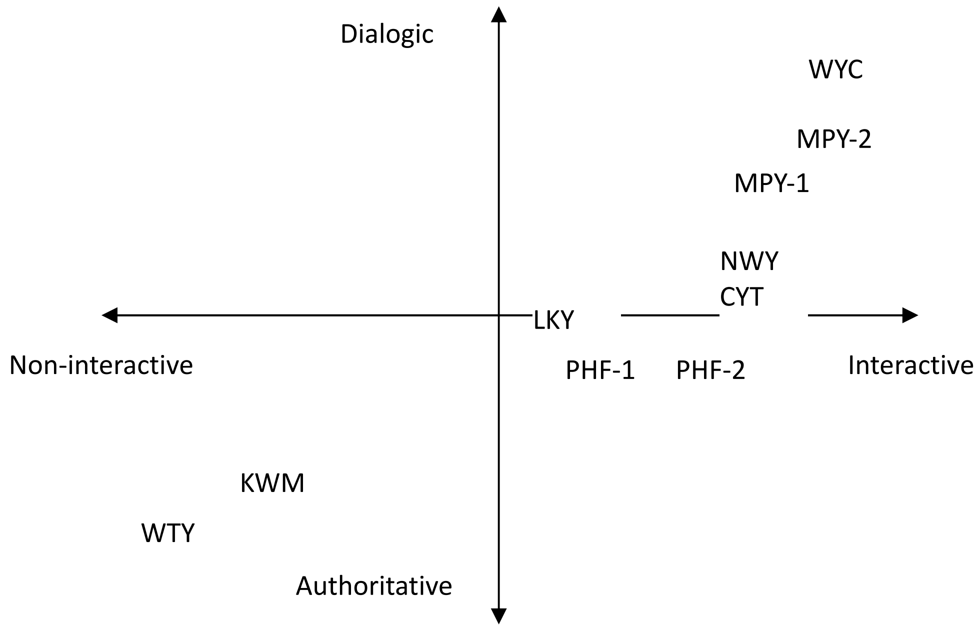

Figure 4.1 Principal communicative approaches of the lessons by each teacher

Based on the data in Table 4.6 and analysis of the classroom talk, the principal communicative approach in each lesson was determined along two dimensions: dialogic/authoritative and interaction/non-interactive (Figure 4.1). The relative positions of the lessons in the figure indicate the extent that a lesson is dialogic/authoritative and interaction/non-interactive relative to other lessons. For instance, the lessons of WYC and MPY-2 were most interactive, but that of WYC involved more open dialogues with student, making it more dialogic than that of MPY-2. The lessons of LKY and PHF were less interactive and more authoritative, involving certain amount of questions and answers without many dialogues. The lessons of KWM and WTY, on the contrary, were dominated by one way teacher talk, making them the most non-interactive and authoritative among all lessons. The judgments of the principal communicative approach, however, are highly interpretive and were independently made by another science educator to enhance its validity.

As shown in Figure 4.1, most of the lessons observed were interactive to some extent, but spread out widely on the dialogic/authoritative dimension. The participants' emphasis of interaction was probably a result of what they learned in the NOS teaching course - effective NOS teaching must engage students in questions. However, teacher-student interactions were mostly limited to probing of simple ideas from students. Unfortunately, students' ideas were seldom elaborated, developed, challenged, and worked on thereafter. Under most circumstances, the teachers took the lead in class discussions, as shown by the scarcity of student-initiated talk and questions in class, and by the near absence of group discussion and talk among students (Table 4.6). The causes of this kind of limited, superficial "dialogue" during NOS teaching are likely twofold: *pedagogical* and *conceptual*. The pedagogical cause refers to the general inability and/or lack of intention of teachers to discourse with students effectively in class, whereas the conceptual cause pertains specifically to NOS teaching in which the high cognitive demands of NOS aspects make teachers "handicapped" during discourses. For the exchanges of LKY and WTY as shown above, constraints in effective discourses are probably pedagogical, in which both teachers just asked a few closed questions and then hurried to provide their "official" answers. Seemingly, they were not interested in knowing what the students were thinking about, and they deliberately chose to keep dialogues brief and closed. On the other hand, some teachers, such as MPY, NWY, and

CYT, were highly dialogic in class when talking about science concepts and the historical science stories. However, in addressing NOS aspects, the dialogues had become limited, brief, and shallow. They did attempt to keep and extend the dialogues with students, but they often balked at students' non-response or responses that were beyond their expectations and understandings. Consequently, the teachers either ended the dialogues prematurely or responded in meaningless and confusing manner. Apparently, in these cases, a teacher's understanding of NOS rather than his/her pedagogy is the main constraint in maintaining dialogues with students. In the exchange below, LKY tried to point out that science is tentative—acid as a cause of ulcers in the past is now replaced by bacteria. She supposed this as an obvious conclusion from the story, but when some students reacted with some unexpected ideas, she seemed not to know how to respond and thus stopped the dialogue. The constraint is likely conceptual as the teacher did not have the understandings that causes can be multiple and possibility is different from probability.

> T: Another thing that I want to say is that scientists used to say that ulcer is caused by hyperacidity. Is it still correct now? Most of the people now believe that ulcer is caused by the bacteria Helicobacter pylori.
>
> S: It is a possibility only, not a must. [An unexpected answer from student]
>
> T: It is a possibility… but there are many studies indicating that ulcer is caused by the bacteria Helicobacter pylori. [Teacher hesitates on how to respond]
>
> S: But you cannot exclude the possibility that hyperacidity is also the cause. [The teacher fails to respond to it and move on.] (LKY-T, 107–110)

As observed, the interactive/dialogic communicative approach seems significantly associated with student engagement in class. Students were actively engaged in the classes of WYC and MPY where communication was interactive and dialogic, but least engaged in the classes of WTY and KWM where most of the teaching was non-interactive and authoritative. It is particularly true for low-ability students as they would easily loss attention in class. A class of disengaged students is bound to have minimal learning outcomes, Hence, an interactive/dialogic communication is crucial for effective NOS teaching.

In summary, the analysis of the classroom talk (Table 4.6, Fig. 4.1) revealed that the communicative approaches of the participants in teaching about NOS were mostly interactive, but not adequately dialogic. This finding corroborates those of other studies (e.g., Bartholomew et al., 2004), and the finding in the previous section that few participants can engage students in reflections of NOS aspects. Students' simple ideas were elicited but not probed deeply, let alone worked on and challenged. The cause of limited dialogues in class is probably both pedagogical and conceptual. Some participants had obvious limitations in their ability and/or intention in maintaining discourse with students, whereas some were limited in discoursing comfortably with students mainly by their NOS understandings. The communicative approach was found associated with student engagement in class, which is probably essential to successful NOS teaching.

CONSTRUCTIVIST PEDAGOGY

This study examines NOS teaching from the constructivist perspectives of teaching and learning. The framework of analysis was drawn from conceptual change models, which were based on personal constructivist perspectives (Appleton, 1997;

Clough, 2006; Posner et al., 1982), as well as models based on the social constructivist perspective (Hewson et al., 1998; Mortimer & Scott, 2003; Ryder & Leach, 2008). In this framework, concept learning is considered to start from meaning making in the social plane through classroom talk, and then internalized into the psychological plane as personal meaning. To produce conceptual changes, teachers have to probe, work with, and challenge students' ideas publicly to create dissatisfaction among them, and then make the newly introduced NOS conceptions intelligible, plausible, and fruitful. These processes have to take place in the contexts of authentic science so that students will not exit the instruction with their ideas about authentic science unaltered (Appleton, 1997; Clough, 2006).

Apart from analyzing the lessons of the participants directly, the constructivist pedagogy of the participants was also evaluated with the *Constructivist Teaching Questionnaire* (Tenenbaum et al., 2001) (see Appendix 1). The students of the participants and the participants themselves completed the questionnaire to show the extent to which the following seven features of constructivist teaching were shown in class: *(1) arguments, discussions, and debates; (2) conceptual conflicts and dilemmas; (3) sharing ideas with others; (4) materials and resources targeted toward solution; (5) motivation toward reflections and concept investigation; (6) meeting students' needs; (7) making meaningful, real-life examples.* The results are shown in Table 4.7.

Table 4.7 Constructivist pedagogy of the teachers as assessed by their students and the teachers themselves with the Constructivist Teaching Questionnaire (Tenenbaum et al., 2001).

	Total	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Students							
CYT	3.11	3.06	2.87	3.22	3.05	3.21	3.36
(n=40)	(0.85)	(0.76)	(0.97)	(1.01)	(0.65)	(0.56)	(0.78)
NWY	2.93	3.05	2.53	2.78	2.99	3.03	3.08
(n=69)	(1.12)	(1.23)	(1.28)	(1.19)	(1.24)	(1.23)	(1.25)
LKY	3.16	3.24	2.27	3.37	3.14	3.36	3.38
(n=62)	(0.60)	(0.71)	(1.00)	(0.86)	(0.77)	(0.75)	(0.70)
PHF	3.23	3.17	3.00	3.23	3.27	3.31	3.33
(n=23)	(0.62)	(0.76)	(1.01)	(0.61)	(0.79)	(0.79)	(0.96)
MPY	3.33	3.44	2.61	3.41	3.38	3.40	3.61
(n=40)	(0.53)	(0.70)	(1.03)	(0.68)	(0.67)	(0.65)	(0.63)
WTY	3.71	3.84	2.92	3.79	3.76	3.83	3.78
(n=70)	(0.53)	(0.64)	(1.10)	(0.68)	(0.68)	(0.61)	(0.70)
WYC	3.65	3.66	3.52	3.42	3.75	3.71	3.78
(n=38)	(0.67)	(0.58)	(0.41)	(0.55)	(0.49)	(0.56)	(0.45)
KWM	3.10	3.10	2.53	2.97	3.35	3.46	3.13
	(0.65)	(0.89)	(0.56)	(0.83)	(0.56)	(0.78)	(0.79)
Teachers							
CYT	3.00	3.25	2.00	3.50	3.00	3.20	3.50
NWY	3.22	3.20	2.00	3.50	3.00	3.40	4.00
LKY	3.07	3.00	2.00	3.25	3.2	3.23	3.75
PHF	3.19	3.00	4.00	3.25	2.83	3.00	3.50
MPY	3.48	3.40	3.33	4.00	3.20	3.60	3.75
WTY	3.37	3.80	2.67	3.25	2.83	4.00	3.50
WYC	2.67	3.20	2.33	2.50	2.00	2.40	3.75
KWM	3.20	3.75	2.50	3.25	3.00	3.50	3.25

Note: The figures showed the averaged scores of the items. The score of each item ranges from 1-5, with 5 representing that the constructivist principles are most prevalent while 1 the least. The figures in the brackets showed the standard deviations.

The total mean scores of most participants as assessed by their students were slightly above 3 (except WTY and WYC), which, in a scale of 1–5, cannot be said as indicating strong constructivist features. The findings of the questionnaire were generally consistent with the class observations. WYC, the one having the second highest score, was able to work with students' ideas effectively in class through extensive, reflective dialogues. His class showed many features of constructivist teaching. Paradoxically, the teacher with the highest score, WTY, was found to be highly non-interactive/authoritative in class. A probable explanation is that the school of WTY was traditional and the teaching styles of most teachers were didactic and teacher-centered, making WTY a relatively "constructivist" teacher in the eyes of the students. Nonetheless, WTY had exceptionally lower score in Factor 2 (conceptual conflicts), revealing that his constructivist repertoire is probably limited to social interaction.

One thing noteworthy was the significantly lower scores in Factor 2 of all participants, except WYC. Factor 2, conceptual conflicts and dilemmas, is believed to be a unique and more important factor for constructivist pedagogy than other factors (Tenenbaum et al., 2001). This finding is strikingly consistent with what was observed in class. Most of the lessons, despite being interactive to some extent, did not adequately place students in conceptual conflicts regarding the NOS conceptions. They mostly probed students' simple ideas through questioning, but they failed to work with them deeply, let alone to challenge them with conceptual dilemmas. Conceptual conflicts are important conditions for conceptual change in light of naïve NOS views commonly held by students. However, the teachers generally subscribed to the transmissive model of teaching and considered conceptual dilemmas a kind of "bad" teaching. On the other hand, the participants probably also lacked the abilities to create conceptual dilemmas regarding NOS aspects, which demand a sophisticated understanding of NOS conceptions, as well as of students' preconceptions on NOS.

The questionnaire completed by the participants themselves revealed their relative emphasis on the various principles of constructivist pedagogy. Interestingly, consistent with students' results, most of the participants had the lowest scores in Factor 2, which were even lower than that given by their students. Instead, they tended to give themselves high scores in Factor 6, which emphasizes real-life examples and accurate concept understanding. These findings corroborate the conjecture that the participants did not value conceptual dilemmas and considered them a kind of poor teaching. On the contrary, they considered accurate concept understanding of prime importance. These teaching beliefs probably form the barrier to effective NOS teaching that demands constructivist pedagogy.

In general, the findings of the questionnaire lend support to the conclusions based on class observations–the lessons of the participants were interactive to some extent (Factors1 and 3), but did not create much cognitive conflict among students (Factor 2). Therefore, the original pedagogical orientation of most participants, except WYC, is not sufficiently constructivist to support highly reflective NOS teaching. None of the participants used conceptual change strategies, such as prediction-observation-explanation (POE) and concept mapping, to explore and work on students' ideas. Some participants, such as WYC and MPY-1, did attempt to probe students' preconceptions about science at the beginning of the lessons, but the probing was brief and shallow. Moreover, they did not make use of the findings from the probing to inform their teaching thereafter. Below is an exchange where the teacher attempted to place students in a cognitive conflict that scientific theories do not represent "facts". However, the cognitive conflict did not develop as intended because the teacher failed to work with students' ideas through effective questioning.

T: Do you think this asteroid hypothesis [for dinosaur extinction] is still a hypothesis now, or has become an indisputable fact?

S1: Still a hypothesis.

T: Still a hypothesis?

S2: No, it has much evidence.

T: It has much evidence so it is an indisputable fact... Does it really have no dispute? [No students respond then the teacher moves on.] (PHF-T-2)

Constructivist teaching cannot be scripted, and it has to be highly responsive and sensitive to students' reponses to capture the opportunities that emerge spontaneously during the progression of teaching. The two teachers studied by Schwartz and Lederman (2002) showed a difference in that ability. A teacher (WYC), being highly interactive and dialogic in the lesson, reflected that "some questions I planned were probably too open for students to get the focus. But, in general, after some guidance questions were provided, students can have discussions based on the questions" (WYC-R). It reveals that planned questions can not be used in a scripted manner without attending to the responses of students. In the excerpt below, an idea from a student emerged naturally and unexpectedly, but it was not treated seriously by the teacher, so that the golden moment of working with students' thinking was missed.

T: But the Royal Society of Science rejected it. [publication of Jenner's findings] Why? It has been proven!

S: He didn't bribe! [The Royal Society] [Class laugh!]

T: He didn't bribe? Scientists like money? [The teacher does not work on this idea and move on] (PHF-T-1)

Apart from cognitive conflicts, conceptual changes on students' ideas on science depend heavily on whether the NOS aspects are presented to students in an intelligible, plausible, and fruitful manner within authentic science contexts. In that respect, the explicit approach adopted by all lessons constitutes the basic condition for conceptual change – only when the conceptions are possessed publicly could they be changed. Regarding authentic scientific contexts, five out of the ten lessons observed used science history to address NOS aspects (Table 4.2), including Jenner's invention of smallpox vaccines (PHF-1), Fleming's discovery of penicillin (WYC), debates over the causes of dinosaur extinction (PHF-2), discovery of *H. pylori* as the cause of peptic ulcers (LKY), and the development of microscopes and cell theory (CYT). Although these science stories vary in their authenticity due to varying amount of contextual detail provided, the NOS aspects addressed in these contexts are more plausible than those utilizing decontextualized NOS activities (MPY-1, NWY) and scientific content (MPY-2, WTY). In addition, a good story with adequate contextual details, supplemented with attractive photos and diagrams, can be highly engaging to students. Motivational engagement is also an essential condition for conceptual change (Alsop & Watts, 1997) and many participants had noted its importance: "If students are actively participating in the discussion, they could understand the meaning of NOS concepts by themselves….Classroom atmosphere is crucial" (MPY-R).

However, motivational engagement does not mean intellectual engagement regarding NOS learning. The intelligibility and plausibility of NOS aspects depend heavily on how the storylines are crafted and used. The teacher must be able to set appropriate questions at key moments of the story to draw students' attention to NOS aspects. Both PHF-2 and LKY used the teaching resources provided by the researcher so the NOS aspects from the stories were rich and basically plausible. In LKY's lesson, a host of NOS aspects were addressed in the context of Marshall and Warren's discovery of *H. pylori* as the main cause of peptic ulcers. The storylines were carefully constructed so that they were adequately rich to make the NOS aspects plausible, but not overwhelming to students. Warren's first discovery of *H. pylori* in the stomach provides an invaluable context to address the theory-laden nature of observations. As initiated by the question: "Why did no one find the bacteria before?" students were convincingly shown a case of theory-laden observations–past scientists failed to "see" the bacteria because they held the "theory" that no bacteria can survive the stomach's acids, even though they might have come across the bacteria. Marshall and Warren's subsequent experimental work to prove the relationship between bacteria and ulcers can powerfully illustrate how science is made reliable through rigorous experimentation. On the other hand, the initial rejection of Marshall and Warren's findings by most gastroenterologists, Marshall drinking the bacteria himself, and the final award of the Nobel Prize to them all vividly revealed the humanistic and social side of science, the tentative nature of scientific knowledge, and the collective objectivity of the scientific community achieved through peer critiques. These rich contexts of authentic science, coupled with appropriate reflective questions, are powerful in producing conceptual change in students' understanding of science.

However, for CYT and PHF-1 who developed their own teaching plans utilizing science history, both the diversity and intelligibility of the NOS aspects addressed by the stories were greatly discounted. In PHF-1, only two NOS aspects were targeted in the story about Jenner's discovery of smallpox vaccines: theory-laden subjectivity, and differences between observation and inference. However, both were not persuasively addressed in the story. He had the students entangled with an ambiguous question: “After having cowpox, people would not get smallpox. Is this an observation or an inference?” (PHF-T-1, 1) It is both, depending on whether the statement refers to an individual event or a universal generalization. In addition, he missed the rich NOS aspects embedded in the story: the sociocultural influences on the acceptance of Jenner’s findings, and the profound contributions science brings to humans as exemplified by the eradication of smallpox by vaccination. CYT’s whole lesson was devoted to only one NOS aspect—the relationship between science and technology, which, however, was presented to students through the simple idea that microscopes and the cell theory are developing together. The more important understandings about the differences between science and technology and their relationships, however, were largely untouched.

Another limitation of historical stories in addressing NOS aspects is the tendency of students, or even teachers, to view history retrospectively from the contemporary perspectives—a “whig” view of history (Brush, 1974). To avoid this, teachers must be able to provide adequate historical background for students and explicitly remind them regularly to think from the shoes of the people at the time. In the lesson of PHF-1, he tried to show students that scientists are biased by their knowledge background: scientists at the time of Jenner failed to understand his work due to the lack of knowledge on immunity. However, as students already had some commonsense knowledge about immunity, they simply found it difficult to realize why other scientists rejected Jenner’s findings. In another lesson by PHF-2, he wanted the students to appreciate that proposing the asteroid hypothesis for the extinction of dinosaurs from a layer of iridium in soil is really creative (PHF-T-2, 62–68). However, some students seemed unconvinced: “If I know it [iridium] is in the asteroids, I can think of it immediately.” This is an obvious example of “whig” view of history in which the students thought it was logical and straightforward to think of the asteroid impact because they already had rich knowledge about asteroids and their connections with dinosaur extinction. Their contemporary knowledge makes them fail to realize the creativity in drawing upon something extraterrestrial to explain the dinosaur extinctions in the 70s, which is like a science fiction! A similar example can be found in NWY’s lesson, in which she showed students Leeuwenhoek’s drawings of sperms with small humans inside. She attributed the drawings to the limitations of microscopes, rather than to the *preformation theory* prevalent at the time of Leeuwenhoek. As such, the plausibility of theory-laden observations was greatly discounted as a kind of technological fault. The above issues can be avoided, or at least reduced, by providing students with adequate historical details. For example, asteroids were not well known in the 70s, and one in the size that can kill all dinosaurs was simply unimaginable. In addition, many people in the 17th century believed that the whole mini-human already existed in germ cells, and they did not have any concepts about genes and genetic materials we know today.

As seen from the above analyses, we can see that it would be a great challenge for teachers to develop historical cases that can illustrate NOS aspects convincingly to students, which requires not only an in-depth understanding of NOS, but also an immense knowledge of the history of science. This makes NOS teaching through science history vary considerably in its effectiveness, depending very much on the richness of the story and the plausibility of the NOS aspects drawn from it. This explains why most of the highly simplified, haphazard science stories in the textbooks do nothing with students’ NOS understandings. Therefore, success in NOS teaching through history can only be possible, at least at the initial stages, by providing teachers with quality teaching resources appropriate to their students and own curricula, such as those provided to LKY and PHF-2. However, this kind of quality teaching plans that utilize the history of science is largely unavailable, and this constitutes one main barrier to the realization of effective NOS teaching in classrooms. However, as seen from the case of WYC, he successfully developed the story on his own to address a host of NOS aspects. His success shows that, with enough effort and enthusiasm, it is still possible for teachers to develop quality historical stories to teach NOS effectively.

As has been discussed in Chapter 2, the lessons utilizing decontextualized, content-free NOS activities (MPY-1 and NWY) have inherent limitations in their effectiveness in promoting conceptual changes in students' NOS conceptions. In addition, the teachers seemed not to realize the nature of these activities as analogies for authentic science; hence, they did not make appropriate bridging between the activities and authentic science. Even for the moderately contextualized activities, such as the rough moon surface observed by Galileo, the effectiveness was discounted by the failure to provide enough historical background to make the NOS aspects intelligible and plausible. Scientific content as a context to address NOS carries the same weakness, but it is probably better than the NOS activities because it is closer to authentic science.

Conceptual changes concerning contextual NOS aspects do not automatically lead to similar conceptual changes concerning the general NOS understandings of students, if students do not regard the contexts as representative of authentic science. Therefore, frequent interchanges between contextualized and decontextualized NOS aspects in classroom talk was proposed by Ryder and Leach (2008). However, this kind of talk was not common in most of the lessons (Table 4.5 and 4.6), and the participants seemed not to do that intentionally. Generalization can also be made by applying NOS aspects to more examples in authentic science. A successful application of a NOS conception in wider contexts can increase its fruitfulness and status (Hewson & Thorley, 1989), which in turn facilitates conceptual change. In Table 4.6, the numbers of *illustration* show the examples each teacher used to illustrate NOS aspects further. NWY's lesson contained the most illustrations because she used six activities/examples to illustrate one NOS aspect (i.e., theory-laden observations). However, it still did not make the NOS conception more intelligible and plausible because she did not make explicit bridging between the examples and all the examples used were not authentic science. The illustrations of WTY and KWM were even worse. They just mentioned examples, such as Newton's laws, but they did not explain at all how the examples can illustrate NOS aspects.

In conclusion, the NOS teaching of the participants was generally not showing strong features of constructivist pedagogical principles, particularly for creating conceptual conflicts among students. If students' preconceptions are incompatible with or even contradictory to NOS aspects to be learned, the teaching will likely lead to the undesirable scenarios envisaged by Clough (2006, p.469-470), that is, reinforcement of students' existing ideas or parallel existence of both old and new ideas. As for the intelligibility and plausibility of the NOS aspects delivered, historical contexts of authentic science are superior to decontextualized or moderately contextualized NOS activities. However, NOS teaching in the context of science history should pay attention to how the story is crafted and presented. The NOS aspects have to be highly plausible in the story and students should be prevented from appraising the events from contemporary perspectives. The historical cases developed by the teachers themselves were often unsatisfactory in this regard. On the other hand, generalization of the contextualized NOS conceptions to wider contexts of science were seldom intentionally and effectively made, which may jeopardize the plausibility and fruitfulness of the NOS aspects to students.

KNOWLEDGE AND SKILLS NEEDED FOR NOS TEACHING

The findings and analyses in the previous sections shed important light on the research questions of this study: *What knowledge and skills that science teachers need for NOS teaching?* This study deliberately seeks to examine the knowledge and skills that are needed for NOS teaching, instead of the intentions, motivations, and attitudes of teachers. In the model proposed by Schwartz and Lederman (2002, p. 233), the *knowledge* base for NOS teaching is clearly distinguished from *beliefs* and *intentions* (Fig. 2.2). Although knowledge and skills intertwine inextricably with beliefs in the instructional decision making of science teachers as shown in the *Sociocultural Model of Embedded Belief Systems* of Jones and Carter (2007, p. 1074) (Fig. 2.3), knowledge and skills are considered to be at the heart of the belief systems regarding NOS teaching. A teacher's practice in the classroom is construed as a reflection of his/her knowledge and skills rather than his/her beliefs and attitudes, except when evidence indicates otherwise. Nonetheless, the attribution of the teaching practice to knowledge and skills is necessarily interpretive, although evidence has been sought from multiple sources. Three knowledge bases are examined below: knowledge of NOS, knowledge of the contexts for NOS teaching, and pedagogical knowledge for NOS teaching.

Knowledge of NOS

The findings of this study support the conclusion that the single most significant factor that affects a teacher's NOS teaching is probably his/her understanding of NOS. Many of the classroom teaching practices also have their roots in the teachers' NOS conceptions, including how NOS aspects are explicated and communicated in the classroom, as well as the teaching design and general teaching approach employed.

The imperative role of the NOS understanding of teachers in NOS teaching is revealed by the fact that a substantial amount of NOS aspects explicated by participants in the classroom were inaccurate and even erroneous. These inaccurate or erroneous explications of NOS aspects in class were obviously caused by teachers' inadequate understanding of NOS. Addressing NOS aspects correctly and accurately is the basic requirement for effective NOS teaching.

The inadequate NOS knowledge of teachers is likely to stem from the issues pertaining to general and contextual NOS understanding. All the participants of the study showed "informed" NOS conceptions as assessed by the SUSSI questionnaire, but some of them failed to address the NOS aspects accurately in class. For instance, NWY showed "informed" views in *Observation and Inference* in SUSSI and can explain theory-laden observations clearly in general statements, but still fail to explain it accurately with the examples she used in class. In another example, PHF explained the differences between observations and inferences in class as "observation is what you see…. Inference often involves subjective judgments… that implies observation often has no dispute" (PHF-T-1, 27), but, in the SUSSI, he agreed that "scientists' observations of the same event may be different" (Q1A). In general, the participants were more able to address NOS aspects in general statements than in specific contexts.

This discrepancy between general and contextual NOS understanding can be conceptualized as a *transfer* problem. If NOS understanding is highly *context bound* (Clough, 2005; Southerland et al., 2005; Ryder & Leach, 2008), a teacher who learns the NOS aspects in general statements or within limited contexts needs to transfer the general NOS understandings to the novel, specific contexts of his/her own classes. This transfer barrier helps explain why some teacher can only address the NOS aspects in general statements and terms in class. A case in point is the lesson of WTY in which he only talked about scientific laws and theories in general statements as those in SUSSI, but he did not elaborate them with the Mendel's laws. The above findings lend support to the notion that the "adequate" NOS understanding of teachers as assessed by the NOS instruments is far from adequate to support effective NOS teaching, which needs an in-depth, accurate NOS understanding grounded in the specific contexts used for teaching.

Apart from a direct influence on how NOS aspects are explicated in class, the NOS understanding of teachers, and/or their confidence in their NOS understanding, likely exerts tacit influence on their instructional design. Many of the participants (e.g., LKY, CYT, MPY, and NWY) expressed lack of confidence in their own NOS understandings in the self-reflections and interviews. They admitted that this influenced their decision making in planning lessons. They tried to "play safe" by planning lessons with the "least" requirements on their NOS understanding. For LKY and PHF-2, they chose the "safest" approach: using the teaching resources provided by the researcher. LKY admitted that she did not prepare much for the lesson, and she just read the teaching materials two days prior to the lesson. For PHF, although he developed his own lesson plan in his first NOS teaching, the unsuccessful experience made him choose the teaching plan provided by the researcher in his second teaching session.

NWY and MPY-1 chose to use the more simple decontextualized NOS activities, by which only a few simple NOS aspects were addressed in non-science contexts. The lessons of CYT, WTY, and MPY-2, on the other hand, were dominated by content teaching, but were infused with a small amount of NOS aspects. Many of the participants admitted that they avoided addressing complex NOS aspects in authentic science contexts that may lie beyond their understanding of NOS. The only exception was WYC, who devoted much effort in developing a lesson plan to address a host of complex NOS aspects with the case of Fleming's discovery of penicillin. The quality of the lesson plan together with his competent execution made the lesson generally successful. He said in the interview that he did many readings on NOS during his preparation for the lesson, enabling him to arrive at a good grasp of NOS conceptions in the story. It shows that, without adequate efforts put in as WYC, the limited NOS knowledge of teachers will significantly constrain their choice of contexts and approaches for NOS teaching.

Similar to the overall instructional design, the NOS understanding of teachers also limits the NOS aspects they can extract from contexts. Many of the participants in this study, particularly those who developed their own lesson plans, could only address a few NOS aspects in the historical cases or NOS activities, leaving many valuable NOS aspects untouched. For instance, the story of Jenner's discovery of smallpox vaccines should be an excellent example illustrating the complex interplay of science, society, and culture, but PHF used it mainly to address the differences between observation and inference. He admitted he failed to "see" these NOS aspects in the story when the researcher pointed them out during the interview. Apparently, his limited NOS understanding prevented him from uncovering the NOS aspects in the story, which in turn jeopardized the richness of NOS aspects addressed by the lesson.

The NOS conceptions of a teacher not only affect the instructional design of a lesson, but it may also affect the communicative approach that a teacher employs. The communicative approaches taken by participants, as shown in Figure 4.1, might be associated with their NOS understanding. WYC, the teacher showing the most sophisticated NOS understanding, taught in the most interactive and dialogic way. He was able to discourse comfortably on NOS aspects with the students, which was not possible without a good grasp of the NOS aspects. His lesson was even more effective than those of LKY and PHF-2, who used the teaching resources provided by the researcher. It was probably because, among others, the process in preparing for the lesson made WYC internalize the NOS aspects much better than LKY and PHF did. Consequently, WYC discoursed confidently with students, whereas LKY and PHF-2 only relied on the scripts provided and taught in a more authoritative manner.

Many participants of this study, such as CYT, NWY, LKY, and MPY, started class discussions openly but soon became closed and authoritative when the NOS aspects went beyond their "control." These teachers seemed not didactic in their ordinary teaching about science content, but they all admitted that the unfamiliar and abstract NOS aspects significantly constrained their interactions with students, forcing them to address NOS aspects in a relatively didactic manner. The dialogic/authoritative dimension appears to be more associated with participants' NOS understanding than the interactive/non-interactive dimension. Teachers having more adequate NOS views (WYC and MPY) tend to be more able to teach in a dialogic manner. On the contrary, an authoritative communication approach in class often reflects a teacher's inadequate NOS understanding or a low confidence in teaching NOS (LKY, WTY). This association, however, is only loose and subject to the interaction of other factors. KWM has adequate NOS conceptions as shown in his teaching and in the interview, but he taught in a mainly non-interactive/authoritative manner, probably because of his own teaching belief, or oddly, his being too enthusiastic in talking about NOS aspects.

Closely associated with the dialogic communication is the ability of teachers to respond to students' spontaneous reactions regarding NOS. In a lesson (PHF-2), when the teacher mentioned "hypothesis," a student asked at once "False?" (The Chinese meaning of hypothesis is "false claim.") The teacher, however, ignored the student and missed the valuable opportunity to teach about the meaning of hypothesis. His non-response was probably pedagogical, but it was also likely a result of his inadequate understanding of the meaning of hypothesis. Hence, a teacher with limited NOS understandings is only able to address NOS aspects "prepared" in advance, but fails to address the NOS aspects that emerge unexpectedly while interacting with students, making the teaching non-constructivist and non-reflective.

In conclusion, the findings of this study support that NOS understanding of teachers is the most significant factor affecting most of the teaching practices in class, including how NOS aspects are explicated (contextualized/general, accurate/naïve, abundant/scarce, or simplified/in-depth), what contexts/activities are chosen to exemplify NOS aspects (history of science, decontextualized NOS activities, or scientific content), and what communicative approach is employed (dialogic/authoritative). All these practices are closely associated with the effectiveness of NOS teaching. This conclusion, however, is inconsistent with the conclusion reached by other NOS researchers (Abd-El-Khalick & Lederman, 2000a; Bartholomew et al., 2004) that teachers' understanding of NOS is just one, yet not the most important one, of the factors that affect NOS teaching practice. As has been discussed in Chapter 2, this conclusion is problematic in that it relies on NOS instruments and interviews to judge the NOS understanding of teachers to the exclusion of examination of their teaching about NOS in classrooms.

Pedagogical knowledge for NOS teaching

Effective NOS teaching demands a teacher to have the knowledge and skills to address NOS aspects in a constructivist manner in general, and engage students in reflective, epistemic, and metacognitive discourses in particular. In this study and in many others (Abd-El-Khalick & Akerson, 2003; Bartholomew et al., 2004; Ryder & Leach, 2008), teachers have been found to have limited abilities in this respect, especially in engaging students in reflective discourse and creating cognitive conflicts. Even when questions were provided in the teaching resources for some lessons (LKY and PHF-2), the dialogues initiated thereafter were often limited in depth and length (Table 4.6). Students' ideas were often probed superficially in IRE patterns, and not worked on adequately. The communicative approach, despite fairly interactive, is not adequately dialogic (Figure 4.1).

The limited reflective dialogues as observed in the classes of the participants may stem from teachers' incompetence and/or their pedagogical intentions. However, it appears that many of the participants tried to maintain the dialogues in class, but they stopped prematurely as a result of students' passive responses and/or their inability to respond to students. Seemingly, the cause of the inadequate dialogues appears more pertaining to teachers' inadequate skills and knowledge rather than their intentions. This is corroborated by their self-reflections and interviews in which many of them agreed on the importance of having reflective dialogues with students.

> it's difficult to elicit the student responses… it's important to capture the

responses of students…and keep the dialogue…this experience [NOS teaching] is important…. this gives me more confidence (PHF-I, 58-1:00).

Discussions are the most effective one. … is the dialogue among students and teacher. …If students are actively participated in the discussion, they could understand the meaning of NOS concept by themselves. (MPY-R)

In teaching NOS, the most difficult is to guide them [students] to think with questions. As I don't have much experience, I'm afraid they will go too far from the *answers*, and I can't get them back. Besides, it is very difficult to make use of the answers from students to stimulate others to think, making me to have dialogue just with a few students. (CYT-R)

Actually they learned in the NOS teaching course that reflective dialogues are at the heart of effective NOS teaching, and they were modeled on how to make reflective dialogue. However, as revealed by the Constructivist Teaching Questionnaire, the existing pedagogical approaches of most participants' were not constructivist, particularly for cognitive conflicts and dilemmas (Factor 2) (see Table 4.7). By contrast, most of them subscribed to the transmission model of teaching that emphasizes accurate delivery of concepts. This discrepancy between their existing pedagogy and the requirement of effective NOS teaching constitutes the main barrier for them to have reflective discourses with students in class. For example, in the above excerpt of CYT, she was mostly concerned with how to get students back to the "correct" answers, rather than probing and working with their thinkings through dialogues. The knowledge and skills in this respect, after all, cannot be acquired easily through the 2-month NOS teaching course because they pertain to the fundamental pedagogy and beliefs of teachers. On the other than, the teacher (WYC) who showed strong features of constructivist pedagogy as assessed by the questionnaire, could teach NOS effectively through extensive, reflective discourses in class. His existing pedagogical beliefs and abilities are probably pivotal in his success.

On the other hand, for some teachers, such as MPY, NWY, LKY, and CYT, their communicative approaches appeared to be limited more by their NOS understandings than their ability to maintain dialogues with students. They showed their competence in discoursing with students when dealing with subject matters and other teaching activities, implying that they were not lacking the general abilities to make their teaching dialogic, but these abilities were compromised when addressing NOS aspects that were both difficult and unfamiliar to them. Nonetheless, some teachers, such as WTY and PHF, appeared to have neither intentions nor abilities to maintain dialogues with students. Hence, teaching NOS dialogically and reflectively is a double challenge for them.

In the study, the teaching experiences of the teachers did not facilitate NOS teaching. The teacher with over fifteen years of teaching experience (KWM) taught NOS poorly, whereas the new teacher, WCY, could effectively teach NOS. Nonetheless, this observation is not conclusive because most of the participants were new teachers with less than three years' experiences of teaching. The more significant factor appears to pertain to the existing pedagogy of individual teachers, rather than their teaching experience. On the contrary, experienced teachers accustomed to didactic teaching is even more difficult to change their pedagogical practices for NOS teaching.

Knowledge of the contexts for NOS teaching

Effective NOS teaching has to be conducted in contexts, be it the history of science, scientific content, socioscientific issues, scientific investigations or content-free NOS activities. Sound knowledge of these contexts is definitely a crucial requirement for the designing and enacting effective teaching plans. However, as seen from this study, most of the participants did not have adequate knowledge of the contexts they used to teach NOS, particularly the history of science. Consequently, when the teachers developed their own historical cases, the historical background was highly simplified (e.g., CYT, PHF–1), making the NOS aspects unintelligible and implausible to students. For example, in the lesson of NWY, she showed students Leeuwenhoek's drawings of sperms in which there were mini-humans. She just attributed it to the limitations of microscopes without mentioning the *preformation theory* in the 16^{th} century. In MPY's lesson, she explained why people did not accept Galileo's discovery that the moon surface was not perfectly smooth. She did mention the influence of Aristotle's theories, but she neither explained what Aristotle's theories are, nor the profound influence of the religious tenet in the 16^{th} century that all heavenly bodies "must" be perfect. Even when the historical story is provided to teachers, inadequate understanding of the context also constrains teachers to use it effectively. In the lesson of PHF-2, the teacher tried to persuade students that the scientists proposing the asteroid theory of dinosaur extinction was really creative. However, students seemed generally not persuaded, seeing it as a logical inference. This is because the teacher had not provided sufficient contextual details—scientists did not know much about asteroids at the time, and an asteroid in the size that can exterminate most of the organisms on earth was even hardly imaginable in the 70s. These examples all show that a teacher's inadequate knowledge of the history of science leads to the oversimplification of contexts, which in turn jeopardizes the intelligibility and plausibility of NOS aspects delivered to students.

Are the simplified treatments of the stories pedagogical decisions by teachers to deliberately keep the story short? In the interviews, most of the participants were surprised by the contextual details pointed out to them, and they acknowledged that this information could illustrate the NOS aspects much more persuasively. Nonetheless, a few of them insisted that so much contextual details may overwhelm students, and they chose to teach NOS in a neat manner. A teacher (LKY) expressed in her self-reflection that:

> I have not done anything special to add extra information in the lesson because I did not want the class and also the topic to be too complicated for the students and hoped this could raise the students' interest. (LKY-R)

Participants' knowledge of the contexts for NOS teaching also affected their choice of the contexts and examples. In this study, none of the participants used scientific investigations and socioscientific issues to teach NOS; they admitted that they did not have the skills and knowledge about these contexts. Science contents are probably the most familiar context for science teachers. However, the teachers generally found it difficult to identify the NOS aspects in science contents. When a teacher was suggested to try to teach NOS through the Calvin cycle of photosynthesis in the interview, she said "I just don't know how it came" (LKY-I). In a case study of two teachers (Schwartz & Lederman, 2002), one faced great difficulty in recognizing NOS aspects in science contents, whereas another one was more competent in it. The researchers of the study attributed the difference to the subject knowledge of the two teachers. This conclusion, however, is inconsistent with the findings of this study. A teacher with a PhD in biology (WTY) still failed to explain scientific laws accurately with Mendel’s inheritance. Subject knowledge, when pertaining to conceptual understanding only, does not help with the understanding of NOS aspects in science concepts; instead, knowledge of how science concepts come is more important for NOS teaching, which pertains more to the history of science.

To conclude, good knowledge of the contexts for NOS teaching, science history, scientific investigations, socioscientific issues, and even decontextulaized NOS activities, is essential for effective NOS teaching. Of particular importance is the knowledge of the history of science, which is the source for the knowledge about the social aspects of science, the process of science and the development of science. Teachers generally lack adequate knowledge in these aspects and are thus seriously constrained during the planning and actual teaching of NOS. The most straightforward solution to this problem is to provide teachers with quality teaching resources accompanied with detailed contextual information and teaching notes. A study (Ruder & Leach, 2008) shows that, when teachers are merely provided with extensive teaching resources, they can teach NOS effectively. Nonetheless, as has been discussed in Chapter 2, the availability of this kind of NOS teaching resources is limited.

Summary

The findings of this study lend support to the notion of Schwartz and Ledmeran (2002) that the knowledge bases for NOS teaching are composed of knowledge of NOS and pedagogical knowledge for NOS teaching. However, the third knowledge base they propose, subject matter knowledge, was found insignificant in NOS teaching. Instead, knowledge of the contexts for NOS teaching, particularly the history of science, is much more important. These knowledge bases constitute the necessary or even sufficent conditions for effective NOS teaching. Among the three, knowledge of NOS is probably the most significant one, which effects permeate every aspect of NOS teaching.

The influence of these cognitive factors appears to be consistent among the teachers irrespective of their academic background, teaching experience, gender, subject to teach and student characteristics. However, the original pedagogical orientation of teachers appears to play a significant role in NOS teaching. A teacher who is more constructivist in his/her ordinary teaching tends to be more effective in NOS teaching, given other factors being the same.

In the next chapter, the findings of this chapter are examined for their practical and reseach implications. A model for effective NOS teaching is constructed. The limitations of the study are also discussed.

Chapter Five

Conclusion and Recommendations

A microscopic analysis of the ten lessons from eight Hong Kong secondary science teachers has provided valuable insights to many important issues pertaining to NOS teaching. First, the findings help build a comprehensive framework for NOS teaching to answer the research question: *What are the key characteristics of NOS teaching that are conducive to NOS learning?* With such a provisional framework, the NOS teaching practice of teachers can be described and evaluated to address two more research questions: *How do a group of secondary science teachers in Hong Kong teach NOS in classrooms after attending a course on NOS teaching? To what extent do the teachers demonstrate these key characteristics in their NOS teaching?* The answers to these two questions further illuminate the central research question of this study: *What knowledge and skills do science teachers need to possess in order to demonstrate these key characteristics of NOS teaching?* As detailed explorations of these questions have already been presented in Chapter 4, this section will attempt to draw some general conclusions based on the previous analyses.

The framework for effective NOS teaching is first described in detail, after which the NOS teaching practice of the participants against this framework are discussed to shed light on the knowledge and skills constraining their practice. The limitations of the study and implications for future NOS research and practice are discussed at last.

FRAMEWORK FOR NOS TEACHING

One important contribution of this study to the research and practice of NOS teaching is the establishment of a theoretical framework to characterize NOS teaching that are conducive to NOS learning. Although existing studies have also provided some recommendations on ways to teach NOS, these recommendations often fall short for being vague, simple, or restricted to one aspect of NOS teaching. For instance, the *explicit, reflective* approach, albeit widely advocated to be effective, is too general and vague to provide practice and research directions. An explicit attention to NOS aspects during instruction is a fundamental and necessary condition for effective NOS teaching; however this alone is far from sufficient to reveal the characteristics of NOS teaching. First, the explicit approach does not give due considerations of the contexts, which may have significant impact on the effectiveness of NOS teaching. More confusing is the meaning of “reflective.” Lederman (2006, p. 312) explains it briefly as follows:

> To encourage *reflection*, teachers must discuss with students the implications, such aspects of NOS and scientific inquiry, have for *the way they view scientists, scientific knowledge, and practice of science.*

This account of reflective teaching is somewhat similar to the epistemic, metacognitive discourse that requires students to reflect on, evaluate, and justify their ideas about science (Abd-El-Khalick & Akerson, 2003; Bartholomew et al., 2004; Smith et al., 2002). However, as explained in another article (Schwartz and Lederman, 2002), “the *reflective* component involves the application of these tactics in the context of activities, investigations, and historical examples…” (p. 207). As such, “reflective” NOS teaching is simply teaching NOS in contexts as compared to direct explication of NOS aspects, which is significantly different from the previous definitions that require students to examine their own NOS views. In addition to its ambiguity in meanings, this kind of reflective, epistemic, and metacognitive discourses regarding NOS teaching has seldom been depicted and exemplified with actual classroom excerpts in empirical studies. Thus, an explicit, reflective approach, as advocated by NOS literature, is largely empty in the sense that it is limited in informing teachers on how to teach NOS effectively, as well as in informing NOS researchers on what counts as effective NOS teaching.

This study has first established a provisional theoretical framework for NOS teaching through the synthesis of the literature, particularly drawing upon the works of Bartholomew et al. (2004), Clough (2006), and Ryder and Leach (2008). Based on the empirical findings of this study, this provisional framework was further developed and elaborated into a final framework consisting of six dimensions: A. Accuracy of the NOS aspects, B. Intelligibility and plausibility of the NOS aspects, C. Explicitness /reflectiveness of NOS teaching, D. Contexts for NOS teaching, E. Communicative approach of NOS teaching, F. Congruence with existing curricular and assessment goals. Instead of providing a merely descriptive account of NOS teaching, this framework attempts to put the various characteristics of NOS teaching in continua. The characteristics towards the right end of each continuum represent the NOS teaching practices that are supported by theories and/or empirical findings of this study and others to be more conducive to NOS learning. These six dimensions are not independent; rather, they intertwine in complex manners.

Table 5.1 Theoretical framework for NOS teaching

Dimension A: Accuracy of the NOS aspects

low → high

Naïve NOS aspects	Oversimplified NOS aspects	Accurate NOS aspects in contexts	Accurate NOS aspects for science in general

Dimension B: Intelligibility and plausibility of the NOS aspects

low → high

Decontextualized NOS aspects explicated in NOS tenets without elaboration	NOS aspects richly illustrated in contexts	↔	NOS aspects generalized from contexts to science in general

Dimension C: Explicitness/reflectiveness of NOS teaching

low → high

Implicit - no explicit talk on the NOS aspects	Explicit talk on *contextualized* NOS aspects	Explicit talk on *general* NOS aspects	Engagement of students in *reflection* of their own ideas about the NOS aspects

Table 5.1 Theoretical framework for NOS teaching (continued)

	Dimension D: Context of NOS teaching	
Unauthentic science	⟶	Authentic science
Decontextualized NOS activities	Science inquiry activities Science concepts	Science history socioscientific issues
	Dimension E: Communicative approach	
Teacher's ideas only	⟶	Students' ideas are made public and worked with
Non-interactive/authoritative	Interactive/authoritative	Interactive/dialogic
	Dimension F: Congruence with existing curricular and assessment goals	
Standalone NOS teaching	⟶	Seamless integration with existing curricular contents

The first dimension of the framework is the accuracy of the NOS aspects explicated in class, which is likely the most fundamental requirement for effective NOS teaching. The provisional framework and the literature only describe the NOS conceptions delivered by teachers as either naïve or informed, but this final framework refines the accuracy of NOS aspects into four types based on the class observations of the study. The naïve NOS aspects are often made when the teachers attempt to explain the NOS aspects *in context*. For instance, MPY portrayed science as relativist, whereas NWY equated theory-laden observation with imagination and technological limitations. The second type is oversimplified, though correct, NOS aspects in general statements. Most of the participants had no great difficulties in delivering these NOS statements "correctly" in class, but these oversimplified NOS statements are far from "accurate." For instance, there is nothing wrong when a teacher explained that "law and theory are at the same level. Laws are describing things, theory explains things. Law does not come from theory, while theory does not come from laws" (WTY-T, 54). However, this excerpt is oversimplified in that it does not address many questions crucial to understanding scientific laws and theories, such as *How are laws and theories different from our everyday descriptions and explanations of things? Where do laws come from if they are not coming from theories? What is meant by "laws and theories are at the same level"?* In addition, these general statements often have significant exceptions in particular contexts (Alters, 1997a; Clough, 2005). However, even when the teacher can accurately explain NOS conceptions in a particular context, sometimes the NOS conceptions may be biased for science in general. For instance, in the lesson of PHF, students were shown that both the theories of asteroid impact and volcano eruption can adequately explain dinosaur extinction, accurately illustrating the problem of underdetermination of scientific theory and thus the limitations of science. However, most, though not all, of the well–established scientific theories do not have an alternative and equally sound counterpart as in this case. Many important scientific theories are well agreed upon by the majority of scientists to be the best available, albeit still underdetermined, explanations of natural phenomena. Thus, the case of dinosaur extinction can accurately illustrate a facet of the nature of science; however, it is not representative of science in general. If the teacher does not pay due attention to these contextual biases, the delivered NOS aspects would be inaccurate for science in general, though accurate in these contexts. This situation can be avoided by providing a more balanced and holistic account of science in general after explicating the contextual NOS aspects. This represents the most accurate type of NOS aspects on the continuum.

Closely related to the accuracy of NOS aspects is Dimension B: the intelligibility and plausibility of NOS aspects, which is a largely neglected aspect in the literature. Different from the initial framework, the empirical findings of this study allow a further elaboration of the intelligibility and plausibility of NOS aspects into three levels. An accurate account of the nature of science is not necessarily intelligible and plausible to students, particularly when it is in general statements. The findings of this study support that NOS aspects have to be highly contextual in order to be intelligible and plausible to students. However, highly contextual NOS aspects may run the risk of not effecting conceptual change in students' ideas toward authentic science if students do not consider the contexts representing authentic science. This is particularly true for decontextualized NOS activities. For instance, in the lesson of NWY, she convincingly used the gestalt pictures to show students that observation was theory-laden, but that alone would be weak to convince students that the observations of scientists are likewise theory-laden. In the contexts of highly authentic science such as the history of science, however, a contextual understanding of NOS aspects seems to be able to generalize automatically, as seen in the lesson of LKY. Nevertheless, a regular interchange between contextualized and general NOS aspects, as suggested by Clough (2006), is most desirable to effect conceptual change in students' NOS understanding.

The Dimension C, explicitness/reflectiveness of NOS teaching, is based upon the well-supported explicit/reflective approach to NOS teaching in the literature. Based on the findings of this study, the provisional framework is further elaborated into four levels. The lowest level is the implicit approach where a teacher merely engages students in inquiry activities or tells them science stories without explicitly addressing the NOS aspects in the contexts. Talking about the nature of science *in general* is construed to be more "explicit/reflective" than that *in context* because it explicitly relates the NOS aspects to whole science rather than a particular incident in science. However, this kind of generalized NOS talk should not be confused with decontextualized NOS talk. The former is a generalization of the contextual NOS aspects, while the latter is a standalone NOS talk not grounded in any context. On the most explicit/reflective end of the dimension is to engage students in reflection of their own ideas regarding science. This is also an indispensable feature that makes the teaching constructivist in order to facilitate conceptual change. In this study, the extent of reflectiveness was operationalized with two types of teacher questions: reflective and metacognitive, which were clearly defined and exemplified by actual classroom excerpts (See Chapter 3). Reflective questions guide students to think about the NOS aspects, whereas metacognitive questions require them to examine their own thinking and justify their ideas about science. Through counting the numbers of the reflective and metacognitive questions the teacher raises in class, a rough idea of the reflectiveness of the teaching can be known.

The Dimension D of contexts for NOS teaching draws on the framework proposed by Clough (2006), which arranges the contexts according to the extent they are connected with authentic science. The more authentic the contexts, the more likely students are to exit the instruction with deep conceptual change in their ideas about science. Science inquiry activities refer to those conducted in school rather than by real scientists; thus, they are considered to be less authentic science than the science history and the socioscientific issues. Based on the empirical findings of this study, a new context is added to Clough's framework: *science concepts,* such as using Mendel's laws to teach about scientific laws and theories, and the fluid mosaic model of cell membrane to teach about the evidence-based nature of science and scientific models. Although the development of science concepts is inevitably connected with the history of science, teaching NOS through science concepts focuses largely on the concepts themselves to the exclusion of the historical and social milieu. This makes science concepts as a context for NOS teaching less authentic than the history of science. Nevertheless, this is probably the least-resistant context for NOS teaching because it also addresses the imperative goal of content learning. However, notably, the relative positions of the various contexts on the dimension are not fixed by nature; rather, they depend on their "authenticity." An open-ended scientific inquiry working on a real natural phenomenon is a more "authentic" science than a highly simplified vignette of science history.

Dimension D, communicative approach, is based on the framework developed by Mortimer and Scott (2003). Bartholomew et al. (2004) develops a similar dimension depicting the discourse for NOS teaching, with closed, authoritative discourse on the one end, and open, dialogic discourse on the other. The findings of this study suggested a third kind of discourse in-between the two ends, *interactive/authoritative*. This study finds that interactive/dialogic teaching seems highly demanding for teachers. Only one participant of this study was capable of communicating with students dialogically. In contrast, the others mostly employed an *interactive/authoritative* approach, wherein the teacher took lead of the discussions and the ideas of the students were not adequately worked with and explored. Nonetheless, interactive/authoritative teaching is still better than non-interactive/authoritative teaching, albeit not as constructivist and reflective as the interactive/dialogic communication. To help judge the communicative approach of the NOS teaching, a tool was developed in this study to code and count the classroom talk (See Chapter 3).

The last dimension is concerned with the congruence of the NOS teaching with existing curricular content. This dimension has drawn on the literature that explores the intentions of science teachers to include NOS in their classrooms, and Ryder's (2008) emphasis of connecting NOS teaching with content. One major hurdle to NOS teaching is the pressure to cover subject matter and cope with examinations (e.g. Abd-El-Khalick et al., 1998, Lederman, 1995). Given the imperative role of science concepts in the instruction and assessment of science, NOS teaching integrated with curricular science content tends to meet with less resistance from science teachers than the standalone NOS teaching. The findings of this study lend support for this notion. Many participants chose to address NOS while teaching the existing curricular content, such as addressing the story of Jenner while teaching immunity, or discussing scientific laws and theories after teaching Mendel's laws of inheritance. However, caution has to be taken not to scarify the depth and richness of NOS teaching in exchange for concept learning in such integrated approach. For instance, the lesson of WTY was dominated by teaching about Mendel's inheritance while NOS aspects were only mentioned briefly in the last few minutes.

This theoretical framework for NOS teaching practices provides a useful tool for NOS researchers to characterize NOS teaching in order to judge its quality based on its process, rather than its products. As such, NOS teaching is no longer treated as a black box in the conventional input-output study; rather, as complex interplay among the six dimensions. This framework also sheds light on the directions of further research, such as the interactions among the six dimensions and their relationships with empirical learning outcomes. For science teachers, this framework provides clear guidelines on the key characteristics of NOS teaching that are likely to facilitate NOS learning. With this framework, science teachers can examine and reflect on their own teaching practice and explore room for improvement. For curriculum developers, particular attention should be paid to dimensions D and F, which deal with how the NOS goals are made congruent with the science curriculum. For instance, the new senior secondary biology curriculum of Hong Kong stipulates some historical discoveries of science as the curricular contents. This kind of curriculum development efforts, if coupled with an equal emphasis in public assessment, would likely make NOS an emphasized goal in science classroom.

KNOWLEDGE AND SKILLS NEEDED FOR NOS TEACHING

As discussed in Chapter 4, three types of knowledge have been found to affect the practice of a teacher in teaching NOS and hence its effectiveness, including knowledge of NOS, knowledge of the contexts for NOS teaching, and knowledge of pedagogy for effective NOS teaching. These knowledge and skills are all closely associated with the framework for effective NOS teaching, as presented in the above framework. Their relationships can be illustrated with figure 5.1.

As seen from Figure 5.1, knowledge of NOS is the factor that affects all dimensions of effective NOS teaching, but the most direct influence is probably on the accuracy and intelligibility of NOS aspects. Knowledge of effective pedagogy for NOS teaching is associated with the abilities of teachers to present NOS aspects intelligibly and convincingly in an explicit, reflective manner through extended dialogues. Knowledge of contexts supports teachers to construct rich, authentic contexts to illustrate NOS aspects, as well as to integrate NOS teaching with the existing science concepts and science inquiry activities.

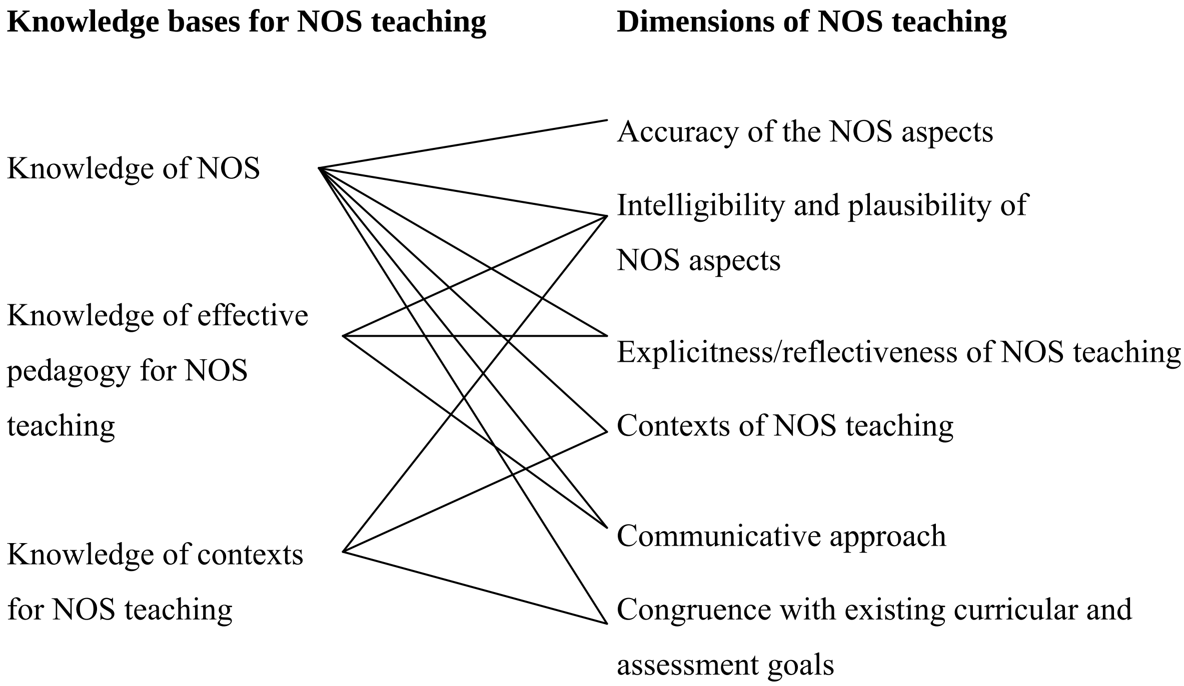

Figure 5.1 Relationships between the knowledge bases and dimensions of NOS teaching

The findings of this study have clearly shown that inadequate NOS understanding is the most significant factor that constrains a teacher from addressing the many key characteristics of NOS teaching as suggested by the framework; however, some NOS researchers may disagree (Abd-El-Khalick & Lederman, 2000a; Bartholomew et al., 2004; Schwartz & Lederman, 2002). With this conclusion, future efforts on teacher education and teacher professional development should place greater emphasis on developing in-depth, contextual NOS understanding among teachers, particularly those in the contexts/contents that are closely associated with the existing science curricula. Only in such way could the transfer barriers of the NOS conceptions be circumvented.

Regarding knowledge of the contexts for NOS teaching, its influence on NOS teaching is manifest, particularly when teaching plans are developed by teachers themselves. The contexts developed by teachers, particularly historical cases of science, often fall short of being too simplified and inaccurate to convincingly illustrate NOS aspects. Although Lederman (2007) contends that the value of history of science for NOS teaching is mostly an “intuitive assumption” (p. 859), this study indicates otherwise with ample amount of evidence. The study (Abd-El-Khalick & Lederman, 2000b) that Lederman cited to support his claim concerns with the effects of the history of science courses at college on the NOS understanding of teachers, and the results show that most of the teachers have little gain in their NOS views after the courses. This study, however, does not pertain to NOS teaching at all. In addition, the little gain in NOS understanding of teachers is expected because the NOS instrument can only address general NOS aspects, and the history of science courses focused on the history without extracting its NOS aspects for reflection. Hence, this study reveals that history of science *alone* is not sufficient to change teachers’ NOS understanding without reflections on its NOS aspects.

Unlike other studies wherein the teachers are more inclined to address NOS through inquiry lab activities (e.g., Bartholomew et al., 2004; Schwartz & Lederman, 2002), none of the participants in this study has taught NOS through lab activities. This is likely because science teachers in Hong Kong are accustomed to conducting recipe-type experiments, rather than open-ended scientific inquiries (Yip & Cheung, 2004). Similarly, science teachers in Hong Kong rarely incorporate socioscientific issues in science teaching. Although the new senior secondary science curricula implemented in 2009 have given due emphasis on science-technology-society -environment (STSE), the SSIs in science curricula mostly focus on technological applications and social implications, rather than NOS. That helps explain why none of the teachers in this study taught NOS through SSIs. Again, this has shown how the knowledge of the contexts affects NOS teaching.

When NOS teaching resources are provided, problems associated with teachers' insufficient knowledge of contexts can get resolved to some extent. However, as the availability of appropriate NOS teaching resources is limited, NOS teaching that heavily relies on these materials would be unsustainable. Moreover, teaching materials have to be adapted and enacted in ways appropriate to the target audience. One teacher in this study used the materials provided by the researcher to teach NOS, but was puzzled by that "I saw how you taught it to us and it works… But when the subjects were different [her students], it didn't work!" (NWY-I).

Nonetheless, expecting science teachers to study extensively the history of science and socioscientific issues for NOS teaching would also be unrealistic. Therefore, research is yet to be conducted regarding the scope and depth of the knowledge of history of science, SSIs, and scientific inquiry that are needed by science teachers in developing effective teaching for NOS.

The pedagogical knowledge and skills for effective NOS teaching pertain to the constructivist pedagogy in general, and reflective, metacognitive discourses in particular. All the teachers of the study knew that reflective discourse is at the core of effective NOS teaching, but they obviously lacked the abilities to effectively engage students in extended discourse so that their lessons were mostly interactive but authoritative. Some teachers are more competent in teaching in an interactive/dialogic manner, which is likely a reflection of their original pedagogical orientation, rather than the outcomes of the NOS teaching course. Therefore, research is needed to explore how teachers' fundamental pedagogy can be made constructivist and dialogic regarding NOS teaching. The existing NOS teaching courses, however, are likely to produce very limited effect in that respect, because it involves a radical shift of the role of the teacher from the transmission of knowledge to the construction of knowledge (Bartholomew et al., 2004), and the teaching behaviors of teachers are quite resistant to change (Clough, Berg, & Olson, 2008).

Drawing on the above discussions, a model depicting the knowledge bases for NOS teaching is proposed, which is adapted from the model proposed by Schwartz and Lederman (2002, p. 232) on the PCK for NOS (see Fig. 2.4). In this model (Fig. 5.1), the *knowledge of contexts* has replaced the *subject matter knowledge* in the original model because the subject matter is only one, among the various contexts for NOS teaching, and is even not the central one. The *pedagogical knowledge* is too general in the original model, and it is elaborated as the ability to work with ideas of students through reflective discourses. For the *knowledge of NOS*, an in-depth and contextual understanding of NOS is emphasized in the model. To emphasize the overarching role of NOS understanding in NOS teaching, knowledge of NOS is denoted by a largest circle in the model.

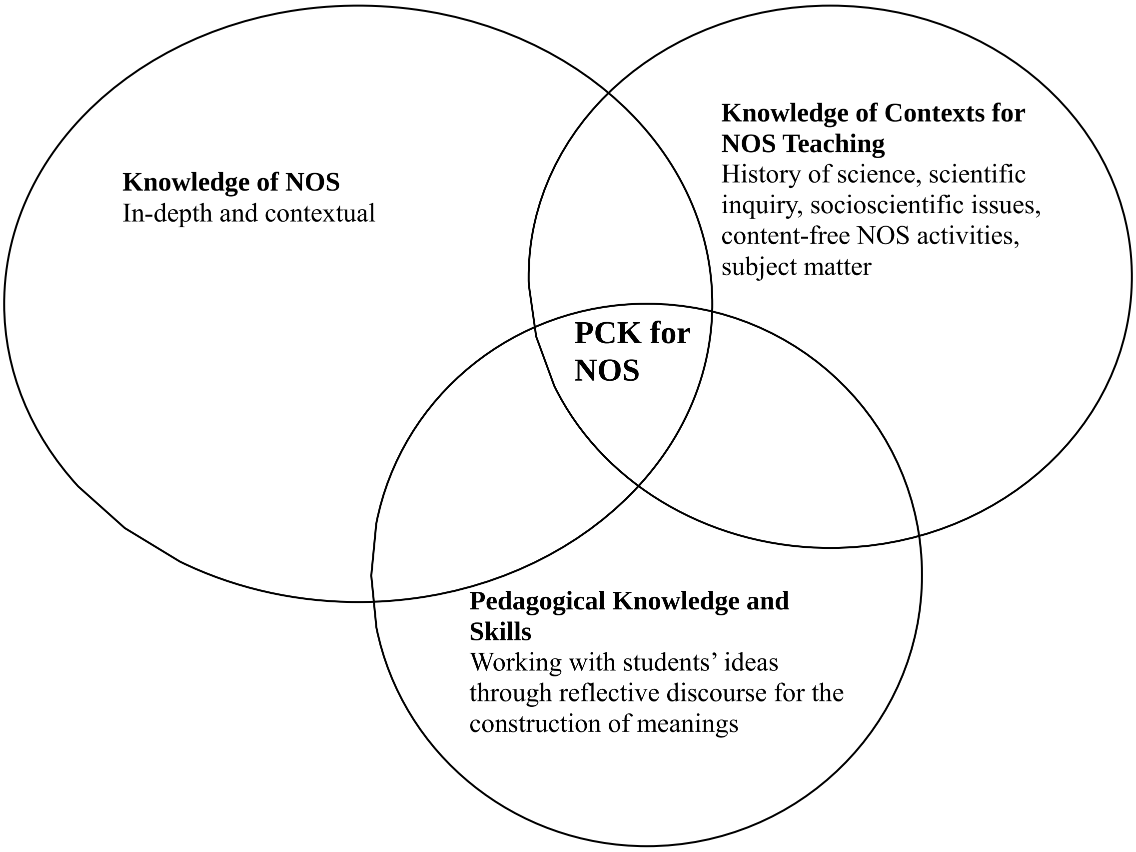

Figure 5.2 Knowledge bases of PCK for NOS (adapted from Schwartz & Lederman, 2002, p. 232. See Fig. 2.4, p. 52)

IMPLICATIONS

In his extensive review on the teaching and learning of nature of science, Lederman (2007, pp. 869–872) raises eleven questions at the end of his article to propose future lines of research. Some questions that are associated with this study are drawn on to discuss the implications of this study.

Closely related to this study is the question: *How do teachers develop PCK for the nature of science?* Lederman raises the question of whether teachers can develop the PCK for NOS, similar to the development of PCK for science concepts. This study shows that teachers are unlikely to develop the PCK for NOS "naturally." Some of the teachers in this study have sound subject matter knowledge (one even has a doctoral degree in biology) and could teach in an interactive/dialogic manner; however, aside from one teacher, most of the teachers still failed to demonstrate the features of effective NOS teaching, even for the teacher with 20 years of teaching experience. The obvious reason is that most science teachers do not possess the knowledge bases for NOS teaching, as depicted in Fig. 5.1. Furthermore, they have no need to develop these domains of knowledge so long as NOS remains merely rhetoric in the curriculum and assessment. Even when teachers are motivated to value and teach NOS, they mostly balk at the lack of teaching resources and supports. Without continued attempts at NOS teaching, the knowledge and skills of teachers would have no way to develop as that of teaching science concepts. Thus, even if given time, the PCK of these teachers for NOS teaching is likely to remain minimal. That explains why, despite 50 years of efforts in promoting NOS teaching, hardly any teachers have been reported and studied for their competent NOS teaching in the NOS literature, such as the exceptional teacher Sister M. Gertrude Hennessey (Beeth & Hewson, 1999). PCK is at the heart of NOS teaching; thus, the above views seem pessimistic with regard to the realization of the NOS goals in science education. This notion is shared by Hipkins, Barker, and Bolstad (2005), who consider NOS as “radical reconceptions” of the curricular goals, and the mismatch between such curriculum reform rhetoric and actual classroom practice is largely *unsolvable*. However, the lessons observed in this study have thrown light on this deadlock; most teachers, when supported by quality NOS teaching resources, were able to show some features of effective NOS teaching, and the student responses were generally positive. Though the teaching was not highly “reflective” and the student responses were not overwhelming, this *modest* level of NOS teaching is likely a more realistic goal to pursue. Nevertheless, even this modest goal would still be unachievable without adequate and suitable NOS teaching resources being made available to teachers.

One question Lederman (2007) raises pertains to the relative effectiveness of the various contexts used for NOS teaching. As seen from the findings of this study, historical case studies are obviously a better choice than the decontextualized NOS activities. Unexpectedly, students showed keen interest in science stories, particularly when these were well crafted and well presented. Research is needed to further explore the effectiveness of the various ways that historical stories are constructed and presented. None of the teachers in the study used scientific investigations and socioscientific issues to teach NOS; thus, their effectiveness in comparison to other contexts has yet to be researched, particularly concerning whether some contexts are especially effective for some NOS aspects.

As for the relative effectiveness of the *subject content embedded* and *non-embedded* approaches, the findings of this study are equivocal. The intuitively advocated embedded approach does not seem to have *a priori* superiority over the standalone NOS teaching, although teachers are more comfortable with it. The effectiveness of the embedded approach depends very much on whether the NOS and the subject contents are seamlessly integrated during teaching. If not, the NOS goals would easily be supplanted by the content learning goals. Therefore, both the embedded and non-embedded approaches are probably needed in a curriculum with an emphasis on NOS.

The above findings and conclusions, nevertheless, are subject to the limitations of the methodology employed by this study. The qualitative nature of the data and case studies design made the conclusions largely interpretive. These conclusions are also limited in their generalizability, although they are generally applicable across the cases and may be generalizable to novice science teachers in Hong Kong. Due to time and resource limitations, only one or two lessons of the eight participants had been observed, which would weaken the credibility of the findings, and render the tracing of the NOS teaching progress of the participants impossible. However, NOS teaching literature generally supports that the teaching practices of teachers for NOS changes little in the study periods, except with intensive on-site assistance (Akerson & Abd-El-Khalick, 2003). Thus, even with one lesson from each participant, this is probably a typical lesson of their NOS teaching. This study did not conduct standardized assessment of the NOS learning outcomes of students; therefore, it does not allow a quantitative comparison of the effectiveness of the NOS teaching by different participants. This is deliberate because the study aims to look at the process, rather than the products, of NOS teaching, and the validity of the standardized NOS instruments is doubtful. Instead, the effectiveness of the NOS teaching is mainly judged by its process through class observations against the framework for effective NOS teaching. Unlike other studies on NOS teaching, this study does not place heavy emphasis on the interview data of the participants because they are mainly concerned with beliefs and intentions. Instead, the focus is on the process of NOS teaching in actual classroom, from which the various underlying factors are inferred.

Despite overwhelming support by science educators and emphases in science education reform documents (AAAS, 1993; CDC & HKEAA, 2007a, 2007b; NRC, 1996), NOS does not seem to enjoy the same status among science teachers. In the light of the largely futile efforts in the past few decades, Lederman (2006, p. 302) holds a pessimistic view that "the current reform documents' emphasis on the NOS and scientific inquiry are likely to have as little impact as earlier efforts." However, my own experiences in this study and teacher professional development courses have sent me a clear message: teachers largely find the NOS interesting and valuable; however, they balk at the lack of the knowledge and skills as well as appropriate teaching materials for effective NOS teaching. These barriers in abilities, in face of the huge pressure to cover the syllabi for examinations, particularly in Hong Kong, makes NOS goals remain largely rhetoric in the science curricula. To break the deadlock, the solution is likely pertinent to the knowledge and skills of teachers, whereas their intentions are secondary. To kick off NOS teaching in science classrooms, it is imperative to develop adequate, quality, and appropriate NOS teaching materials that are closely aligned with local science curricula and public examinations. The provision of these materials, coupled with corresponding teacher professional development efforts, are likely to give some science teachers an impetus to try out NOS teaching, which, over time, could build up a critical mass of expertise to make NOS teaching sustainable. An active, self-initiated and prolonged participation of science teachers in NOS teaching attempts is crucial to explore what effective NOS teaching really means in classrooms. Therefore, science educators and curriculum developers must take a more *pragmatic, bottom-up* approach to NOS teaching: consult and negotiate with science teachers regarding what they need and deem appropriate, rather than spoon-feed them with the NOS goals and materials from the top down.

Appendix 1

Constructivist Teaching Questionnaire Questionnaire

Instruction: According to your teacher's lessons, answer the following questions with 1-5.

	1- not at all **2- little** **3 - somewhat** **4 - much** **5 – very much**
In the class, the teacher encouraged original ideas.	Factor 1– Arguments, discussions, debates
In the class, the teacher always exchanged ideas with us.	
In the class, there were often many perspectives.	
I learned how to think in the class, for example, how to think critically.	
We were allowed for arguments, discussions and debates in the class.	
In the class, the teacher intentionally posed some dilemma for me.	Factor 2 Conceptual conflicts and dilemmas
In the class, the teacher intentionally caused some confusion among our ideas.	
In the class, the teacher intentionally made some conflicts among our ideas.	
The class allowed us to have social interaction.	Factor 3 Sharing ideas with others
The class has a variety of learning activities.	
In the class, I was given sufficient opportunities to express my ideas.	
In the class, I was given sufficient opportunities to share my own ideas with my classmates.	
In the class, I used my knowledge to think abstractly.	Factor 4 Motivation toward reflections and concept investigation
In the class, the teacher guided me to investigate concepts.	
The class motivated me to reflect on some problems.	
The class encouraged me to examine several perspectives of an issue.	
The class motivated me to further my learning on related knowledge.	
The class motivated me to learn.	
I felt pleased with what I learned in the class.	Factor 5

The content of the class took into consideration my needs and concerns.	Meeting students' needs
The class helped me to pursue personal goals in learning.	
The class helped me to benefit from my learning difficulties.	
In the class, the teacher negotiated with us on the learning goals.	
The class addressed real-life events.	Factor 6 Making meaning, real-life examples
In the class, the teacher used rich examples.	
The class focused more on understanding concepts rather than answering questions.	
The class environment encouraged me to think.	

(Adapted from Tenenbaum et al.(2001), with slight change in wording during the translation into Chinese.)

Appendix 2

Student Understanding of Science and Scientific Investigation (SUSSI)

Instruction

Please read EACH statement carefully, and then indicate the degree to which you agree or disagree with EACH statement by circling the appropriate letters to the right of each statement

Key:

SD= Strongly Disagree; D = Disagree More Than Agree; U = Uncertain or Not Sure; A = Agree More Than Disagree; SA = Strongly Agree

1. Observations and Inferences	
A. Scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.	
B. Scientists' observations of the same event will be the same because scientists are objective.	
C. Scientists' observations of the same event will be the same because observations are facts.	
D. Scientists may make different interpretations based on the same observations.	
With examples, explain why you think scientists' observations and interpretations are the same OR different.	

2. Change of Scientific Theories	
A. Scientific theories are subject to on-going testing and revision.	
B. Scientific theories may be completely replaced by new theories in light of new evidence.	
C. Scientific theories may be changed because scientists reinterpret existing observations.	
D. Scientific theories based on accurate experimentation will not be changed.	
With examples, explain why you think scientific theories do not change OR how (in what ways) scientific theories may be changed.	

3. Scientific Laws vs. Theories	
A. Scientific theories exist in the natural world and are uncovered through scientific investigations.	
B. Unlike theories, scientific laws are not subject to change.	
C. Scientific laws are theories that have been proven.	
D. Scientific theories explain scientific laws.	
With examples, explain the nature of and difference between scientific theories and scientific laws.	

4. Social and Cultural Influence on Science	
A. Scientific research is not influenced by society and culture because scientists are trained to conduct "pure", unbiased studies.	
B. Cultural values and expectations determine what science is conducted and accepted.	
C. Cultural values and expectations determine how science is conducted and accepted.	
D. All cultures conduct scientific research the same way because science is universal and independent of society and culture.	
With examples, explain how society and culture affect OR do not affect scientific research.	

5. Imagination and Creativity in Scientific Investigations	
A. Scientists use their imagination and creativity when they collect data.	
B. Scientists use their imagination and creativity when they analyze and interpret data.	
C. Scientists do **not** use their imagination and creativity because these conflict with their logical reasoning.	
D. Scientists do **not** use their imagination and creativity because these can interfere with objectivity.	
With examples, explain how and when scientists use imagination and creativity **OR** do not use imagination and creativity.	

6. Methodology of Scientific Investigation	
A. Scientists use different types of methods to conduct scientific investigations	
B. Scientists follow the same step-by-step scientific method.	
C. When scientists use the scientific method correctly, their results are true and accurate.	
D. Experiments are not the only means used in the development of scientific Knowledge.	
With examples, explain whether scientists follow a single, universal scientific method **OR** use different types of methods	

7. Teaching about history of science	
A. Science teaching at secondary school should include more history of science (more than what the popular textbooks have provided).	
B. History of science can make the teaching more interesting.	
C. History of science can let students understand how scientists think and work.	
D. History of science can let students better understand the science concepts.	
With examples, explain briefly what history of science you have taught in your class.	

8. Teaching about scientific investigation	
A. Engaging students in scientific investigations aims to develop students' **practical skills and abilities** in designing and conducting fair test.	
B. Engaging students in scientific investigations aims to let students understand more about the **nature of scientific investigation**, such as the inference nature of the conclusion, the distinction between data and conclusion, the reasoning underlying the experimental design and its limitations, the theory-laden nature of hypothesis.	
C. Engaging students in scientific investigations aims to verify and consolidate the **science concepts** they learn in class.	
D. Engaging students in scientific investigations aims to add **fun** to science teaching.	
With examples, explain briefly how you typically teach scientific investigation in your class.	

9. Classroom language and science teaching	
A. The language used in science teaching would portray a **wrong image of science** to students.	
B. Science language has to be authoritative, objective, impersonal, and firm.	
C. Science concepts have to be explained to students in a certain, clear and unambiguous manner.	
With examples, explain briefly how you talk about some science concepts typically in your class.	

Taxonomy of Views about Nature of Science and Scientific Inquiry

Aspect	Explanation/Description	Items
Observations and Inferences	Science is based on both observations and inferences. Observations are descriptive statements about natural phenomena that are directly accessible to human senses (or extensions of those senses) and about which observers can reach consensus with relative ease. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.	1A (+); 1B (-); 1C (-); 1D (+)
Tentativeness	Scientific knowledge is both tentative and durable. Having confidence in scientific knowledge is reasonable while realizing that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge. The history of science reveals both evolutionary and revolutionary changes.	2A (+); 2B (+); 2C(+); 2D (-)
Scientific theories and laws	Both scientific laws and theories are subject to change. Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. Scientific Theories are well-substantiated explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have accompanying explanatory theories.	3A (-); 3B (-); 3C (-); 3D (+)
Social and cultural embeddedness	Scientific knowledge aims to be general and universal. As a human endeavor, science is influenced by the society and culture in which it is practiced. Cultural values and expectations determine what and how science is conducted, interpreted, and accepted.	4A (-); 4B(+); 4C(+); 4D(-)
Creativity and Imagination	Science is a blend of logic and imagination. Scientific concepts do not emerge automatically from data or from any amount of analysis alone. Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers. Scientists use their imagination and creativity throughout their scientific investigations.	5A(+); 5B(+); 5C (-); 5D (-)
Scientific methods	Scientists conduct investigations for a wide variety of reasons. Different kinds of questions suggest different kinds of scientific investigations. Different scientific domains employ different methods, core theories, and standards to advance scientific knowledge and understanding. There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, perseverance, and creativity. Scientific knowledge is gained in a variety of ways including observation, analysis, speculation, library investigation and experimentation.	6A (+); 6B (-); 6C (-); 6D (+)

Appendix 3

Class Observation Protocol

Scoring key: 0 – no evidence, 1- little evidence, 2- moderate evidence, 3-extensive evidence

Categories	Elements of effective NOS teaching
NOS aspects taught in lesson	☐ NOS aspects taught are **accurate** and **unbiased**. Notes
Teacher facilitation of NOS learning	☐ Students' **prior and developing NOS ideas** are explored during the teaching. ☐ Teacher creates **cognitive conflicts** of students' NOS ideas. ☐ The NOS aspects taught are **intelligible** to students: Most students can understand them. ☐ Teacher **elaborates** the NOS aspects and provides opportunities for students **to think and talk** about them (rather than merely repeats the simplified NOS statements didactically). ☐ The NOS aspects are **plausible for the specific context** being used: Most students believe that they are likely to be true in that context. ☐ The NOS aspects are **plausible for general, authentic science:** Most students believe that they are also true of authentic science apart from the specific context being discussed. ☐ Teacher emphasizes the **importance/goals of NOS learning** throughout the lesson. ☐ Teacher guides students to **reflect on their talk/thinking** regarding the NOS aspects ☐ Teacher is **sensitive** to students' existing and developing ideas about NOS.

	☐ Teacher facilitates students' **construction of the NOS understandings** through interacting dialogically with students' ideas (rather than teaches the NOS statements didactically). Notes
Communication	☐ Communication in class is **interactive**, involving appropriate proportion of **teacher and student talk**. ☐ Communication in class is **dialogic** – student's ideas are respected and responded, a variety of student ideas come out, and the communicative pattern is largely **Initiation-Response-Feedback-Response-Feedback (IRFRF**…) as opposed to the **IRE** triads. ☐ Teacher actively invites students to **ask questions.** Notes
Assessment of NOS learning	☐ Teacher assesses and monitors students' NOS learning in a systematic and ongoing way in the lesson, and from which the instruction is adjusted Notes
Student response	☐ Students **actively engage** in learning the NOS aspects. ☐ Students show understanding and reflections on the NOS aspects. ☐ Students show **interest and motivation** in learning the NOS aspects. Notes

Appendix 4

Interview Protocol

1. What NOS conceptions you intended to teach in this lesson? Can you explain them to me?
2. Do you think your teaching approach is effective in teaching the targeted NOS conceptions? Do you think students were engaged by your teaching?
3. Do you think you have good dialogue with students? Is dialogue important in NOS learning, you think?
4. To what extent you think your students have learned the targeted NOS conceptions? How do you know you have achieved them (assessment)?
5. What are the difficulties you encountered during planning and teaching this lesson?
6. How do you feel about this NOS teaching experience? Would you try it again?

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