Professional Journals as a Source of Information about Teaching Nature of Science: An Examination of Articles Published in the *Journal of College Science Teaching*, 1996-2012

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Abstract

Recent efforts to reform science education have strongly emphasized the understanding of the nature of science (NOS) as important to achieving broader scientific literacy. Despite the realization that students' understanding of NOS is important, there is a gap between research and practice. In order to teach NOS effectively in pre-college or college classrooms, teachers need appropriate activities, examples, and models of instruction that can contribute towards the development of their pedagogical content knowledge (PCK) for teaching NOS. One widespread and readily-available source teachers may consult to find appropriate models of teaching practice and example activities is professional journals. The present study investigates articles published in the *Journal of College Science Teaching (JCST)* in the years 1996-2012 (total n=47). We explored the extent to which these provide appropriate models for teaching NOS at the college level and the degree to which the information included can serve to inform readers' PCK for teaching NOS. The findings reveal that there is not a diverse representation of examples for teaching specific aspects of NOS outlined in the reforms. Furthermore, we found a discrepancy between recommendations for effective teaching of NOS in the research literature and the approaches advocated in the articles. Few of the articles included the kinds of robust information that could inform college instructors' PCK for NOS, particularly in regard to assessment. The study identifies gaps in the literature to be explored in further research.

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Introduction

The primary goal of science education is to achieve scientific literacy for all students (AAAS, Benchmarks, 1991; 1993; Project 2061). There is widespread consensus among science educators that students' education in science could contribute to their scientific literacy (Bell, Blair, Crawford & Lederman, 2003; Bybee, 1997; Driver, 1996), if that education goes "beyond addressing the content and processes of science to assist students in developing an understanding of the enterprise of science and the nature of scientific knowledge" (Aydin, Demirdogen, Muslu, Hanuscin, 2013, p. 1). It is clear that science educators and researchers who adhere to this belief emphasize that the development of such sophisticated understandings of nature of science (NOS) among students of all ages is crucial for them to make sense of scientific information encountered in everyday life (Driver, Leach, Millar & Scott, 1996), to understand and make decisions regarding socio-scientific issues (Sadler, Chambers & Zeidler, 2004), and to develop appreciation towards science (Hanuscin, 2013). As a result, student understandings of NOS have been an important component of scientific literacy.

Although the notion of developing appropriate understandings of NOS among students holds a prominent place in various policy documents (AAAS, 1990; 1993), position statements of professional organizations (NSTA, 2000), the *National Science Education Standards* (NRC, 1996) and the most recent *Next Generation of Science Standards* (NGSS, 2013), there exists a gap between emphasis of NOS in policy documents and actual classroom practices (Lederman, 2007). Research literature shows that despite the efforts made by science educators to help teachers understand NOS, for teachers to successfully translate that knowledge and understanding of NOS into their classroom practices is yet another challenge (Abd-El-Khalick, Bell & Lederman, 1998). Either classroom teachers struggle to teach NOS ideas consistent with reforms or make it explicit for students to understand NOS effectively (Schwartz & Lederman, 2002).

Another major concern exists between the NOS ideas as articulated in the science reforms and position of NOS in college science curriculum and instruction. Although the goal of college science courses is to underscore the development of scientific literacy (American Association for the Advancement of Sciences, 1993; National Research Council, 1996), these courses place greater emphasis on science content knowledge and process skills rather than learning NOS (Bautista & Schussler, 2010; Karakas, 2009). Researchers have advocated that NOS should be taught explicitly at the college level (Abd-El-Khalick & Lederman 2000; Dagher & BouJaoude, 2005; Dagher, Brickhouse, Shipman, & Letts, 2004; Ryder & Leach 1999) and have suggested that attempts to teach the NOS should be thoroughly embedded within the science content (Brickhouse, Dagher, Letts, & Shipman, 2002). The available literature, however, seems to suggest that teaching and learning NOS is not a common part of undergraduate science curriculum and instruction, and that college instructors could benefit from support in learning how to address this important instructional goal and in developing their knowledge for teaching NOS.

Compared to studies of K12 and teacher education, there are relatively few studies of teaching and learning NOS at the college level. Several of these studies attempt to help college students understand NOS through the history of science (HOS). While exploring the 181 college students' (166 undergraduates and graduates and 15 preservice teachers) change in conception about NOS, Abd-El-Khalick and Lederman (2000) found that teaching the history of science alone does not automatically enhance their views on NOS; instead, explicit instruction about NOS aspects through HOS does so. In another attempt to teach NOS through HOS, post-instruction interviews of preservice chemistry teachers indicated that the use of historical teaching materials is the primary factor contributing to an increase in understanding of NOS (Lin & Chen, 2002). Bautista and Schussler (2010) investigated the effectiveness of teaching NOS through an explicit- reflective approach in an inquiry-based introductory biology laboratory.

They argued that this approach can be easily integrated to inquiry-based science teaching and helps in improving students' self-reported knowledge of NOS.

In order to teach NOS effectively in pre-college or college classrooms, teachers need appropriate activities, examples, and models of instruction (Abd-El-Khalick and Lederman, 2000), which is referred as pedagogical content knowledge (Shulman,1987) for teaching NOS. Researchers emphasize that teachers require pedagogical content knowledge (PCK) for teaching NOS in order to translate their own understanding of NOS into ways to make teaching NOS explicit for their own students (Abd-El-Khalick and Lederman, 2000). Appleton (2006) suggested that the model lessons or "activities that work" can play an important role in scaffolding the development of teachers' PCK for teaching NOS. According to Smylie (1989), professional journals can be considered as one reliable source teachers may consult to find appropriate models of teaching practice and example activities. For example, college instructors who want to improve their own teaching of NOS might consult the *JCST*, published by the National Science Teachers Association (NSTA). Even though the degree to which college instructors may rely on NSTA journals for exemplary lessons cannot be predicted, but the recent NSTA membership count (updated April, 2013) suggest 4,292 members who designated themselves in the college grade level category. Furthermore, the NSTA membership count documented by NSTA in their website currently shows 21,226 teachers, 2,313 professors and 797 scientists as members. Considering the high count of NSTA membership, it is our contention that *JCST* is one readily available source that college instructors may refer in order to find examples of NOS teaching. In this study, we explore the potential of articles in the *JCST* to provide appropriate models for teaching NOS and to contribute to the development of college science teachers' pedagogical content knowledge (Shulman, 1987) for teaching NOS.

Theoretical Framework

Pedagogical Content Knowledge

Pedagogical Content Knowledge (PCK), according to Shulman (1987), is the specialized knowledge that enables teachers to transform disciplinary content into forms that are accessible to and attainable by students. This includes knowledge of how particular subject matter topics, problems and issues can be organized, represented, and adapted to the diverse interests and abilities of learners. Shulman's model has been elaborated upon and extended by other scholars (e.g. Grossman, 1990; Magnusson, Krajcik, & Borko, 1999). Grossman (1990) viewed PCK as being the integration of several knowledge bases including subject matter knowledge, general pedagogical knowledge, and contextual knowledge. Building on Grossman's work, Magnusson et al. (1999) proposed a transformative model of PCK that includes five interacting components: orientations toward science teaching, knowledge and beliefs about science curriculum (goals & objectives/ curriculum and materials), knowledge and beliefs about students' understanding of specific science topics (prerequisite knowledge and student misconceptions), knowledge and beliefs about assessment in science (dimensions of science learning to assess and knowledge of methods of assessment), and knowledge and beliefs about instructional strategies for teaching science (topic-specific activities, e.g., activities for teaching photosynthesis, as well as subject-specific strategies, e.g., inquiry).

PCK for Teaching NOS

In terms of teaching *NOS*, researchers argue that NOS may be viewed as a cognitive, rather than an affective outcome of instruction (Abd-El-Khalick, 2001) and that NOS is as much an aspect of subject matter as are the reactions of photosynthesis or pH (Lederman, 1998). In other words, NOS may also be viewed as a particular *topic* within the domain of science. In addition to an adequate understanding of NOS, Abd-El-Khalick and Lederman (2000) propose that teachers' PCK for NOS would include:

> …knowledge of a wide range of related examples, activities, illustrations, demonstrations, and historical episodes. These components would enable the teacher to organize, represent, and present the topic for instruction in a manner that makes the target aspects of NOS accessible to pre-college students. Moreover, knowledge of alternative ways of representing the aspects of NOS would enable the teacher to adapt those aspects to the diverse interests and abilities of learners…. [T]eachers should be able to comfortably discourse about NOS, design science-based activities that would help students comprehend those aspects, and contextualize their teaching about NOS with some examples or 'stories' from history of science. (pp. 692-3)

This is consistent with the model of PCK as proposed by Magnusson et al. (1999). We chose Magnusson's model as our framework for this study to conceptualize PCK for teaching NOS. This is because the Magnusson et al. (1999) model consists of essential components such as: teachers' knowledge of including NOS in curriculum, knowledge of how their students' conceptualize NOS, knowledge of instructional strategies to choose appropriate activities to address students' misconceptions and enhance student learning about NOS, and their choice of assessments to assess students' understanding of NOS. Given the nature of this study to analyze published *JCST* articles as appropriate models for teaching NOS, we did not include the first component, teachers' orientations toward science teaching, in our framework.

In addition to capturing and articulating teachers' PCK, researchers are interested in how to support teachers in developing PCK. But how do teachers develop this knowledge? Grossman (1990) viewed PCK as being generated and developed through (a) observation of classes whether as a student or student teacher, (b) disciplinary education, (c) teacher education coursework; and (d) classroom teaching experience. Appleton (2006) proposed that elementary teachers also rely on "activities that work" and recommendations from trusted colleagues (Appleton & Kindt, 1999) as a source of PCK. The "activities that work" are perceived by teachers to be effective in that they are hands-on, interesting and motivating for learners, manageable in the classroom, have a clear outcome or result, draw on equipment that is readily available, and lend themselves toward integration. Smylie (1989) reported that one source upon which teachers draw to find appropriate models of activities is professional journals. Given the wide readership and unique focus of the *JCST*, we operated under the assumption that college science instructors, similar to K12 educators, could develop PCK for teaching NOS through model lessons and activities such as those found in the professional literature related to college science teaching.

Methods

Smylie (1989) reported that one source upon which teachers draw to find appropriate models of activities is professional journals. To explore the models of teaching NOS that college instructors might have available to draw upon, we chose to examine articles from the *JCST* published by the National Science Teachers Association (NSTA) of the United States. We therefore operated under the assumption that professional journals may provide a source of "activities that work" as described by credible colleagues whose work had been peer reviewed. The NSTA website (http://nsta.org) provides a digital archive of articles published as early as 1996. We conducted a conceptual analysis in order to understand the potential of articles in professional journals, such as the *JCST*, as a source for informing college teachers' developing PCK for NOS. We relied on Magnusson et al.'s model for PCK as our guiding framework. The specific research questions guiding our study include:

a) To what extent do published articles provide appropriate models for teaching various aspects of the nature of science?

b) To what extent do published articles that portray NOS instruction provide explicit information that can inform teachers' developing PCK?

Data Sources

Though policy documents such as *Science for All Americans* (AAAS) that describe NOS were published as early as 1990, we assumed that teachers today would not have easy access to articles not included in the NSTA digital archive, thus our pool of potential articles was limited to those published since 1996. A total of 47 articles (see Appendix 1) were identified from the two rounds of our search process, 35 articles from the first and 14 articles from the second round of search were identified. Each round of search is described below.

In the first round of the keyword search 'nature of science', we identified 35 articles published between the years of 1996-2012. Of these, two articles were excluded because they did not fulfill the criteria of inclusion/exclusion of articles described below. Therefore, we had 33 articles to focus upon after our first round of search. The second round of search was done with the keyword search of each aspect of nature of science (e.g., creativity). Fourteen articles were found through this means, thus a total of 47 articles were analyzed.

Inclusion/exclusion decisions were based on two criteria: whether the authors explicitly identified one or more NOS learning outcomes (e.g., "…to help students understand science as a human endeavor" or "…to show students that scientific ideas are subject to change") and that the article includes one or more learning activities, which describe actual classroom implementation of NOS instruction. Articles that lacked one or the other were excluded from our analysis (e.g., an article by John Abraham (2004) and Keith Miller and Iris Totten (2009) were excluded because these do not address NOS teaching).

The pool of articles were published as early as 1999, as no articles pre-1999 met our criteria for "activities that work" and as recently as 2012 (see Figure 1). The initial group of articles lagged several years behind the publication of the *National Science Education Standards* (NRC, 1996), which emphasized teaching NOS in K12. The largest number of articles was published fairly recently (specifically in 2009), during which there was a special issue on students' understanding of scientific investigations, science as a process, developing critical thinking skills, and understanding science as a human endeavor.

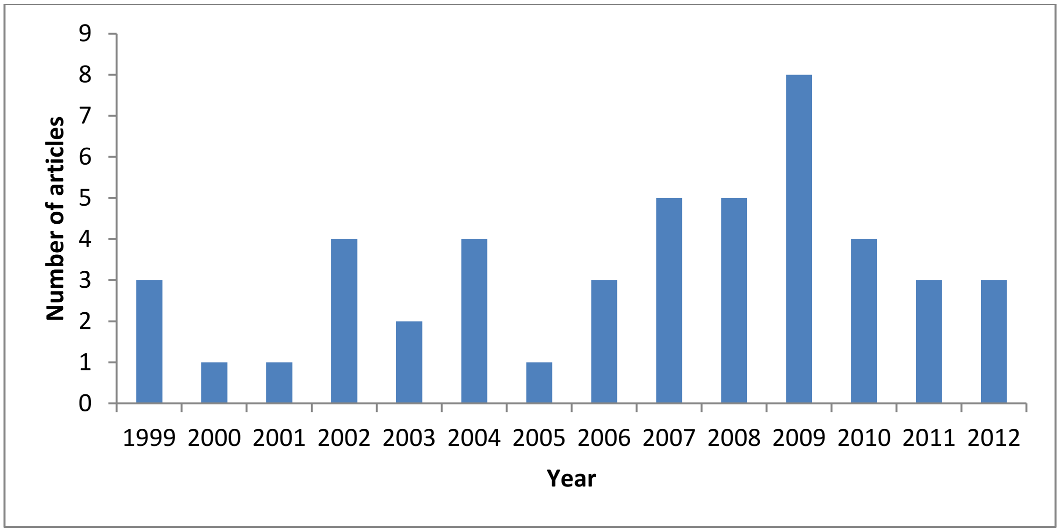

Figure 1. Number of NOS articles (included in our analysis) published by year

Analysis

We conducted a conceptual analysis of the articles, with phrases serving as the unit of analysis. Two separate stages of analyses were performed; the first identified the aspects of NOS targeted by the authors and the second identified information relevant to the development of teachers' PCK for NOS. In the first stage of our analysis, we used aspects of NOS emphasized in the reforms cited below as our initial list of concepts, but also were open to identification of additional and different aspects of NOS as mentioned by authors. While searching for the aspects of NOS in the *JCST* articles as mentioned in the NSTA Position Statement on the Nature of Science (2000), we realized that researchers and authors may use different terms and focus on different ideas that we included as additional aspects of NOS as explained below. Appendix 2 shows example of excerpts from various articles highlighting the NOS aspects. Our initial list was based on those aspects of NOS outlined the NSTA's Position Statement on the Nature of Science (2000), and included the following aspects:

a) Scientific knowledge is both reliable and tentative, or subject to change;
b) No single "scientific method" adequately portrays the diverse methods and means by which scientists study the world;
c) Creativity is vital to the scientific endeavor;
d) Scientific explanations must be based on evidence (empirical nature), and preclude supernatural elements;
e) Scientific knowledge is inferential, and interpreted within a theoretical framework;
f) Scientific knowledge includes theories and laws, which have distinct functions and relationships;
g) Scientific work always has an element of subjectivity; and,
h) Scientific work is influenced, to some extent, by the social and cultural context of the work.

The additional aspects of NOS emphasized in the articles and identified during our analysis included:

i) Science is amoral, which means that scientific knowledge is neither good or bad rather how that knowledge is used or applied is what makes a difference;
j) Science is a human endeavor, and involves many different kinds of individuals; and
k) Communication plays a vital role in scientific work.

All aspects were coded for their presence in an article vs. their frequency of reference. Inter-rater reliability of the coding schema was established through teams of researchers independently analyzing a sample of the articles (6 articles out of a total of 47). Differences in coding decisions were resolved through discussion and negotiation with a third researcher with expertise on NOS, resulting in further refinement of the coding schema.

While addressing NOS in this paper, we have taken the perspective of NOS as suggested in the NSTA position statement (2000). Because the Next Generation of Science Standards (NGSS, 2013) came out recently, it is unlikely that the articles we examined would reflect the NOS ideas as specified in the NGSS (2013). The stance taken by the NGSS (2013) for the NOS clearly suggest that teaching NOS should help students develop appropriate understandings of nature of science that are closely associated with crosscutting concepts and practices of science. The NGSS presents NOS matrix (NGSS, 2013, appendix H, p. 4) comprising of the first four ideas focusing on practices and the last four focusing on crosscutting concepts, as follows:

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge is Based on Empirical Evidence
- Scientific Knowledge is Open to Revision in Light of New Evidence
- Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomenon
- Science is a Way of Knowing
- Scientific Knowledge assumes an Order and Consistency in Natural Systems
- Science is a Human Endeavor
- Science Addresses Question About the Natural and Material World

Though the articles were not analyzed according to the new aspects (NGSS, 2013), most of the aspects, if not all, from our current list that we used in our analysis are closely aligned with the new ideas.

In the second phase of our analysis, we sought to identify relevant information that would contribute toward their developing PCK. For this, we relied on the mode of PCK by Magnusson, Krajcik, & Borko (1999). For example, in analyzing articles for information related to knowledge of assessment of NOS, we searched for discussions of what to assess, as well as examples of specific assessment activities. Specifically, we sought to identify assessments of student understanding of NOS for classroom purposes, as opposed to those assessments used for research purposes. Similarly, in analyzing articles for information related to knowledge of curriculum, we attended to statements about specific learning goals and standards, as well as the mention of specific curricular resources and materials for teaching NOS. Furthermore, in analyzing articles for knowledge of student understanding, we searched for evidence related to the knowledge of areas of student difficulty, strategies attending to their errors and misconceptions and examples of students' thinking. Finally, in analyzing articles we looked for specific instructional strategies for examples of explicit classroom teaching of NOS to gain information on knowledge of instructional strategies. Appendix 3 shows the template used for analyzing each article to find details on each dimension of PCK as suggested by Magnusson et al. (1999).

Findings

Our first research question was concerned with identifying the aspects of NOS addressed in the articles. During the analysis of 47 articles, we looked for a total of 11 aspects of teaching NOS, including the three in addition to the eight aspects outlined in the NSTA's position statement (2000). We were surprised to find that 21 (44.7%) of the 47 articles did not address any specific NOS aspects such as those described in the NSTA position statement or the additional aspects we included in the analysis; rather the articles claimed to teach students about NOS more generally. Within the articles that did identify a specific NOS learning goal, we found there was a diverse, though unbalanced, representation of examples for teaching each of the specific aspects of NOS outlined in the reforms (see Figure 2).

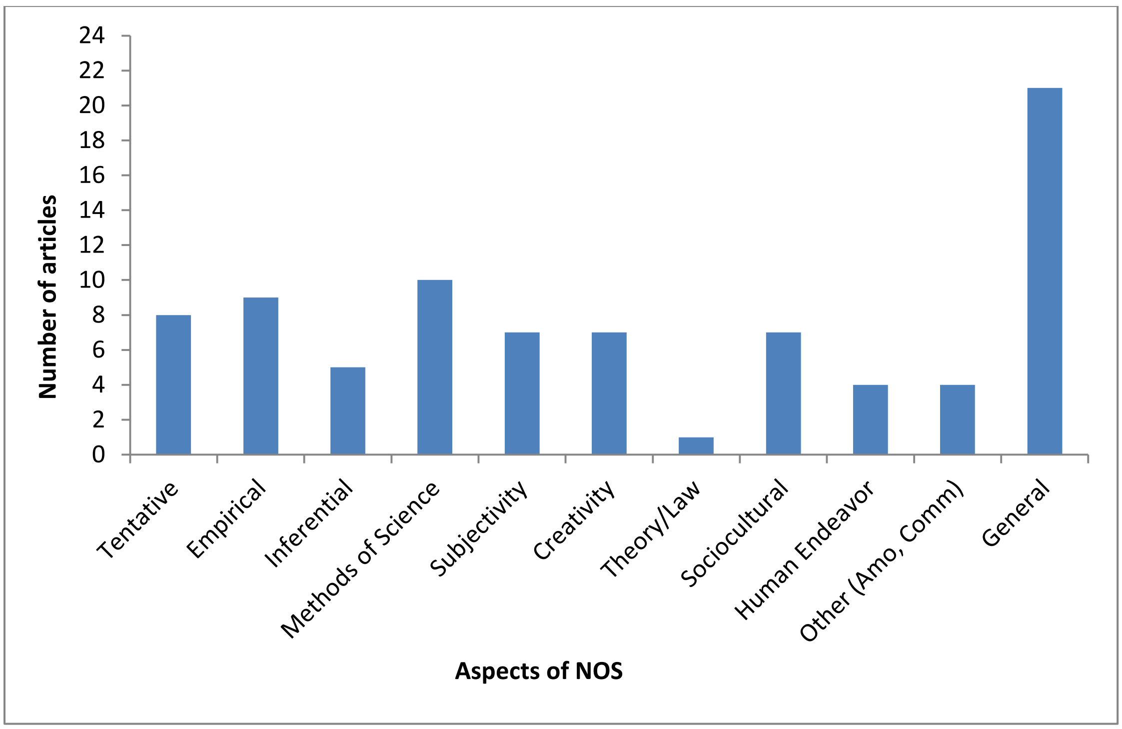

Figure 2. Aspects of NOS emphasized in the analyzed *JCST* articles.

Only one article (2.1%) included information about teaching students the function and relation of theory and law in science, while 10 articles (21.2%) focused on characterizing the multiple and diverse methods of science. The reason for such low frequency of occurrence of the 'theory and law' aspect in the articles is unclear, especially when NOS literature emphasizes that students carry alternative conceptions regarding theory and law that are inconsistent with the understandings of theory and law among the scientific community (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002; McComas, 1996). Two other aspects, the empirical basis of science (19.1%) and tentativeness (17%) are more frequent and all the other aspects of science lag far behind in terms of frequency of occurrence in the *JCST* articles.

Our second research question sought to identify the degree to which articles provide relevant information to support readers' PCK for teaching NOS. We found that among the four components of PCK as suggested by Magnusson et al. (1999) there is least evidence for knowledge of assessment among the articles analyzed as compared to other components of PCK, while information on knowledge of instructional strategies is most evident (see Figure 3).

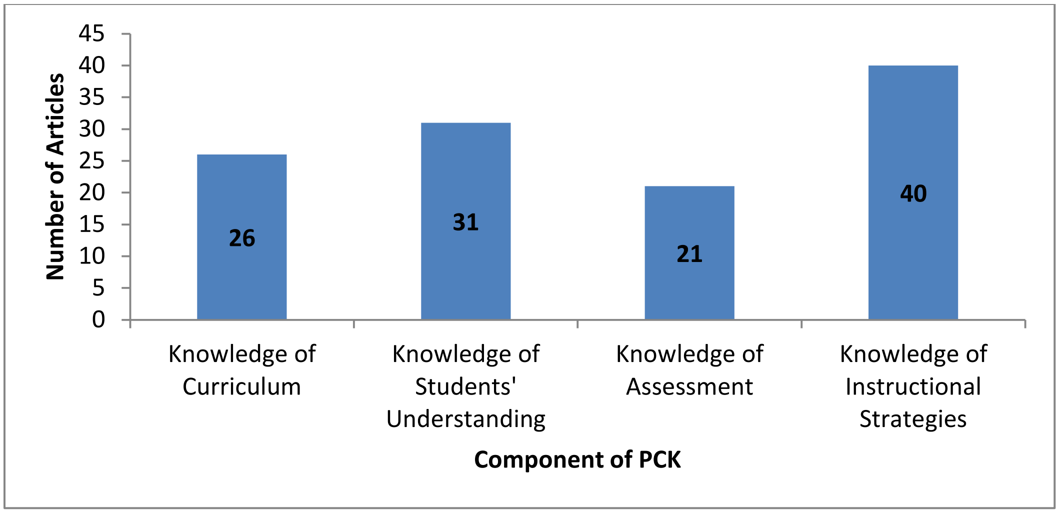

Figure 3. Evidence for components of PCK in the *JCST* articles analyzed.

Knowledge of Science Curriculum

Knowledge of curriculum consists of two knowledge bases. First relates to the knowledge about mandated goals and objectives that are consistent with the national or the state level curriulum and the second about knowledge of specific curricular programs and materials with regard to teaching a particular scientific topic (Magnusson et al., 1999). While analyzing the *JCST* articles,we sought to identify both these knowledge bases, specifically looking for what authors identify as their explicit teaching goals in relation to teaching NOS, as well as what they identify as learning goals for students' understanding of NOS.

Our analysis revealed that 26 out of 47 articles provided clear goals and objectives regarding NOS instruction. In some of the articles, authors clearly stated both the teaching goals as well as the learning goals as to what they expect students to learn about NOS. For instance, in the article by Wilma (2007), one of the lesson objectives for introductory biology students working through case studies was to "appreciate the nature of science and how science affects their lives" (p. 21). The article also provides clear evidence of student learning goals, for instance, "At the end of the case, students should realize that there are no absolute truths in science and that one of the most important outcomes in the process is the generation of new questions, which allows science to continue its course" (p. 22).

In some of the articles, author provided clear evidence regarding their motivation for trying to improve students' understanding of the NOS; for instance, the Dunlop and Hudson (2009) stated that their goal was to improve understandings of the nature of science in a laboratory course for prospective elementary teachers by creating a "scientist-science educator partnerships" (p. 67). They also provided evidence of choosing instructional goals well emphasized by National and State Standards with regard to teaching NOS. They mentioned in their article that "Understanding the nature of science has been an education goal for close to 100 years (Lederman 1992), and it remains a primary objective in the National Science Education Standards (In Dunlop & Hodum, 2009, p. 66; NRC 1996).

Furthermore, we also found authors stating their ideas about specific curricular programs and materials. For instance, Gallucci (2009) emphasizes using case studies in promoting the understanding of NOS in undergraduate classrooms irrespective of the science topic to be taught. Author suggest that "by choosing to teach how scientific knowledge is acquired with authentic case studies, as well as how the scientific enterprise goes about its business, we can promote a more balanced view of NOS in the classroom" (p. 54). In addition to these examples, our analysis also revealed that some articles explicitly stated their curricular goals and learning objectives in context of their educational endeavors.

Knowledge of Students' Understanding of Science

Knowledge of students' understanding of science emphasizes teachers' ideas about how students tend to build their repertoire of scientific knowledge. According to Magnusson et al. (1999), this knowledge base has two categories – understanding of specific needs of students for learning various scientific concepts and areas of student difficulty, their common errors and misconceptions. While analyzing the articles, we tried to identify ways in which the articles portrayed understanding of requirements for students' learning such as their prerequisite skills; understanding of inhibiting factors in their science learning such as misconceptions or lack of connection to common practices.

Our analysis revealed that 31 out of 47 articles showed some evidence of knowledge of students' understanding of science. In some of the articles authors highlighted how a particular teaching strategy helped them get an idea of students' understanding of NOS in their class. For instance, authors emphasized that the jigsaw activity helped the students in an interdiscipinary environmental science course to deepen their understanding of the science topic and to recognize the dynamic nature of science (Edgcomb, Britner, McConnaughay, and Wolffe, 2008, p. 329).

Most of the articles addressing methods of science and creativity clearly stated that college science students have several misconceptions about how scientists work. For instance, in the article by Hohman, Adams, Taggart, Heinrichs & Hickman (2006) the preservice teachers were subjected to open discussion on "what is science and what *isn't* science" (p. 19) to gain as much input from students about their views of scientific knowledge. In addition, in this article creativity is emphasized and evidence is provided demonstrating students' critical thinking on the scientific community and how it works.

We found that some articles provide evidence of knowledge of students' areas of diffficulty or students' preconceptions. In the article by Campbell (2006) students' technology-driven projects were used to enhance the understanding of scientific inquiry and nature of science. The authors' emphasize that students' preconceptions are important for instruction and stated that "Today's college students enter science classrooms having little to no experience with putting into practice the "particular ways of observing, thinking, experimenting, and validating" (AAAS, 1993; p. 16). Similarly, some articles explicitly emphasize knowledge of students' difficulty in understanding of aspects of NOS. In the article Gallucci (2009) clearly points out that when students in introductory biology class were taught nature of science aspects by using case studies, several students had difficulty in interpreting their observations in the proper context.

Knowledge of Instructional Strategy

Knowledge of instructional strategies includes both subject specific strategies (e.g., the learning cycle) as well as topic-specific strategies. These can include representations (i.e., illustrations, example, models, analogies, etc.) as well as activities (i.e., problems, demonstrations, investigations, etc.). This aspect of teachers' knowledge is important for achieving the instructional goals. Teachers need to organize the content into learning activities consistent with the skills and knowledge that the teachers are expected to acquire. In other words, selecting appropriate instructional strategies for teaching is the key to successful teaching.

Analysis of 47 articles revealed that 40 articles showed evidence of some sort of instructional strategies as listed above. Most of the articles addressed NOS in general, along with the science content, rather than focusing on teaching NOS aspects explicitly. In most of the articles NOS is not taught in integration with science topics (content generic) as compared to NOS being taught within the science lesson (content embedded). Though most of the articles have instructional strategy as content generic stating the NOS objectives, but they are not good examples of teaching NOS explicitly. Figure 4 shows the distribution of the type of instructional strategy found in the analysis of 47 articles.

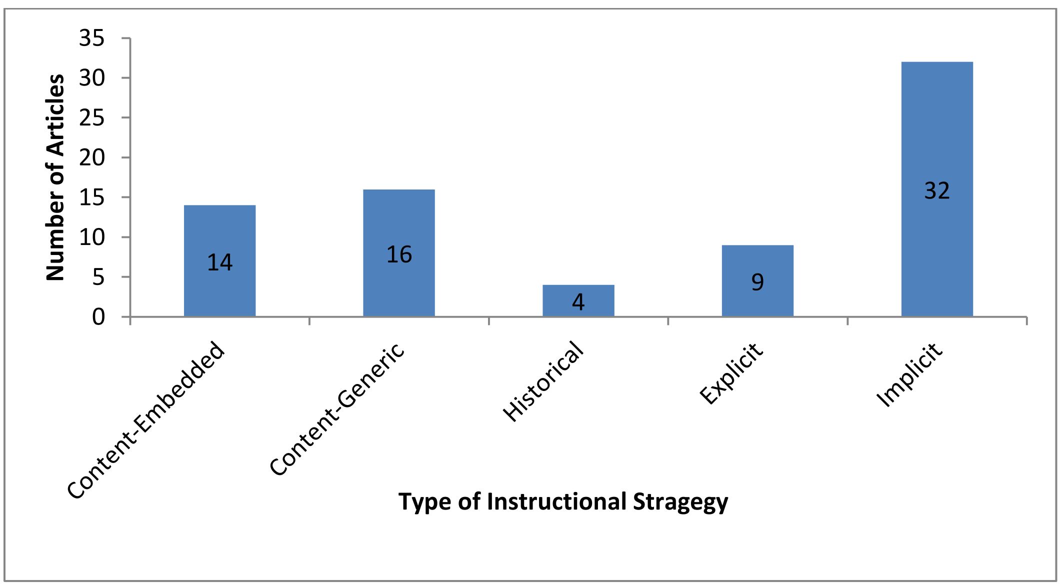

Figure 4. Distribution of instructional strategies for teaching NOS in the articles analyzed

In our analysis, we found that inquiry was emphasized most as the subject specific strategy. There were wide varieties of topic-specific strategies used in the articles to teach various aspects of NOS such as: the ‘New Society activity’ was used to introduce nature of science aspects in a biology non-majors class (Cavallo, 2008); historical case studies were used to understand history and the process of science in an introductory biology class (Susan, 2009), and student-driven investigation and project-based lab reports helped college students to understand scientific method and nature of science along with biology content knowledge (Lunsford, 2002).

Knowledge of Assessment

Knowledge of assessment, as put forward by Magnusson et al. (1999), consists of two categories – knowledge of areas of science learning of students that are “worth assessing” and ways of evaluating students’learning. Therefore, our analysis focused on finding evidence in the articles on what should be assessed in a particular learning experience and the methods of assessment. In our analysis we found only 25 articles that showed evidence of how to assess students’ knowledge.

We also found that instead of assessing the students’ understanding of any particular aspect of NOS, most of the articles used the survey method for assesment. Some of the articles assessed students’ understanding by administering pre-post questionnaires to students. The information from questionnaires was used only for research purposes without further reflection.
However, we do not mean to say that assessing NOS as a whole is not desirable, instead assessment of interconnectedness of the various tenets of NOS, which makes it an umbrella term would be worthwhile. For example, Edcomb et al. (2008) assessed both the prior knowledge of the education majors entering an integrated inquiry-oriented science course and their final gains after the class through a Likert-scale survey assessing “their confidence in their ability to teach science, their understanding of the nature of science, and gender stereotyped beliefs about science” (p. 24). This method of assessment does not provide the complete picture of the individual students’ conceptual understanding of various NOS aspects. However, some of the articles implemented multiple ways to assess students’ understanding throughout.

Kattoula, Verma and Martin-Hansen (2009) also assessed the preservice science teachers’ understanding of NOS in an algebra-based physics course in three different ways. The first probe assessed students’ understanding of NOS using an open-ended survey modified from the original VNOS/VOSI instrument (Lederman et al., 2002); the second probe was used to capture their understandings of NOS using concept mapping and the “last probe was an administration of daily questions related to physics and NOS understandings” (p. 22). Similarly, Schibeci and Murcia (2000) used three different methods to evaluate changes in preservice elementary teacher education students’ conceptions of NOS in an introductory physical science course. These were follow-up open- ended questions, self-evaluation questions like “What have you learned about science as discipline through your involvement in the physical science unit?” (p. 208) and true-false choice items such as “There are fixed steps that scientists always follow to lead them without fail to scientific knowledge” (p. 207).

Discussion and Implications

Within the various domains of teacher knowledge, understanding of NOS can be considered part of teachers’ subject matter knowledge—more specifically, their syntactic knowledge of science, which includes knowledge of the source and justification of scientific knowledge. Appleton (2006) proposed that teachers also rely on "activities that work" and recommendations from trusted colleagues (Appleton & Kindt, 1999) as a source of PCK. However, the critical question is: Do these journal articles, which are potential sources for "activities that work," offer appropriate models for how to teach NOS?

Our findings illustrate that the existing pool of articles related to teaching NOS in the *JCST* is fairly limited; only a handful of articles are available that provide examples of teaching particular aspects of NOS. Assuming that college teachers may refer to activities provided by the *JCST* to inform their teaching, they might not be able to locate relevant information for teaching specific aspects of NOS for their students from this limited pool. This is significant because research indicates that college students hold a variety of misconceptions about NOS (Huhman et al, 2006). Explicit and reflective approaches to teaching about NOS in college science courses are not only important for understanding college students' views about NOS, but also necessary step for achieving scientific literacy for all students (Bautista and Schussler, 2010).

An additional concern is that over half of the articles in our sample failed to provide appropriate models of explicit approaches to teaching NOS. While several researchers emphasize that NOS teaching should be in integration with science content (Brickhouse, Dagher, Letts, & Shipman, 2002), others recommend that whether content-embedded or content-generic, NOS teaching should be explicit (Abd-El-Khalick & Lederman 2000). This notion indicates an approach in which NOS learning outcomes are specifically planned for, taught, and assessed. However, we found the majority of articles did not reflect this explicit approach, and that few included specific examples of how to assess students' learning outcomes in relation to NOS. Therefore additional articles providing examples of explicit and successful NOS teaching at the college level are necessary in order for teachers to refer to *JCST* as one of the reliable resources for teaching NOS effectively.

Furthermore, analysis of the specific types of information included in the articles reveals that few provide comprehensive and robust accounts that could inform the development of readers' PCK, in particular their knowledge of how to assess NOS. Hanuscin, Lee, and Akerson (2011) point out that K12 teachers' use of assessment practices for NOS have remain largely unexplored in the literature. In our analysis of the literature on college teaching of NOS, we found this to be true as well. Few articles provided specific classroom-based assessment strategies that college instructors could utilize to evaluate students' learning of NOS, and specifically how assessment of NOS might be considered part of students' overall course grades. Some researchers have emphasized that assessment of understanding of the nature of science should not focus on students' ability to construct generalizations that hold true at all times and places, but on their ability to identify the evidence associated within their inquiry (Dagher & BouJaoude 2005). Examples of this, in practice, are needed.

While there continues to be a gap between research and practice in terms of teaching and learning about NOS (Lederman, 2007), we argue that professional journals can play an important role in closing this gap, but that in order to do so, authors and editors should attend to specific frameworks, such as PCK, to inform the scope and content of articles. In all fairness, we must acknowledge that neither the intent of authors was to introduce PCK for NOS, nor did the editorial guidelines for *JCST* encourage that; however, given the fact that PCK for NOS is critical for teachers to teach NOS editors and reviewers could encourage authors to include articles that impact readers' PCK for NOS. Careful attention should be paid to the alignment of teaching approaches with the literature, particularly in regard to the explicit teaching of NOS. Our study examined the potential of articles to support college science instructors' PCK for teaching NOS; further research is needed to explore the extent to which this potential is realized, and to examine how professional journals may provide a scaffold for the development of college instructors' PCK.

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Appendix 1: The list of the *JCST* articles analyzed (by year)

Year	Selected articles
1999	Schibeci, R. A., & Murcia, K. (2000). "Science is about facts," or is it? Tien, L. T., Rickey, D., & Stacy, A. M. (1999). The MORE thinking frame: guiding students' thinking in the laboratory. Tolman, D. A. (1999). A science in the making course for nonscience majors.
2000	Allchin, D. (2000). How not to teach historical cases in science.
2001	Choe, S. W. T & Drennan, P. M. (2001). Analyzing scientific literature using a jigsaw group activity.
2002	Dinan, F. J. (2002). Chemistry by the case: integrated case teaching and team learning. Druger, M. (2002). It all depends a perspective on science teaching at all levels. Druger, M. (2002). Teaching the introductory college science course. Lunsford, E. (2003). Inquiry in the community college biology lab: a research report and a model for making it happen.
2003	Demers, N. E. (2003). Issues in science and technology: student-driven inquiry directed by the scientific process. Trautmann et al., (2003). Online peer review.
2004	Abraham, J. (2004). Multidisciplinary explorations bridging the gap between engineering and biology. Cavallo, A. M.L., Rozman, M., Blickenstaff, J., & Walker, N. (2004). Learning, reasoning, motivation, and epistemological beliefs. Meers, M., Demers, N. E., & Savarese, M. (2003/04). Presenting the scientific process. Padamsee, H. (2003). Crossing boundaries: A liberating course for nonscience students.
2005	Grant, R. H. (2005). A strange fish indeed the "discovery" of a living fossil.
2006	Campbell, T. (2006). The distant exploration of wolves using technology to explore student questions about wolves. Hohman, J., Adams, P., Taggart, G., Heinrichs, J., & Hickman, K. (2006). A "Nature of Science" discussion. Connecting mathematics and science. Sales, J., Comeau, D., Liddle, K., Khanna, N., Perrone, L., Palmer, K., & Lynn, D. (2006). Bridging the gap: A research –based approach for teaching interdisciplinary science to undergraduate freshman students.
2007	Lord, T., Shelly, C., & Zimmerman, R. (2007). Society for college science teachers: putting inquiry teaching to the test-enhancing learning in college botany. Parrilla, W.V.C. (2007). Cell phone use and cancer: a case study using the scientific method. Thompson, S. (2007). Demonstrating inquiry-based teaching competencies in the life sciences: part 1 Thompson, S. (2007). Demonstrating inquiry-based teaching competencies in the life sciences: part 1 Yang, Li-H. (2007). A candle lights the way to scientific discourse.

2008	Cavallo, A. (2008). Experiencing the nature of science: an interactive, beginning-of-semester activity. Edgcomb, M., Britner, S. L., McConnaughay, K., & Wolfe, R. (2008). Science 101: An integrated, inquiry-oriented science course for education majors. Varelas, M., Plotnick, R., Wink, D., Fan, Q., & Harris, Y. (2008). Inquiry and connections in integrated science content courses for elementary education majors Williams, J. (2008). The scientific method and school science. Wise, K., & Bluhm, W.J. (2008). Scientific observation and the learning cycle: burning the candle at both ends.
2009	Borda, E. J., Kriz, G.S., Popejoy, K. L., Dickinson, A. K., & Olson, A. L. (2009). Taking ownership of learning in a large class: group projects and a mini-conference. Demers, N. E., (2009). Structure-function lab in a bag. Dunlop, C.M., & Hodum, P. (2009). Scientist-science educator collaborations: do they improve students' understanding of the nature of science? Gallucci, K. (2009). Learning about the nature of science with case studies. Kattoula, E., Verma, G., Hansen-Martin, L. (2009). Fostering preservice teachers' "nature of science" understandings in a physics course. Miller, K., & Totten, I. (2009). Developing and implementing an interdisciplinary origins course at a state university. Muench, S.B. (2009). The mystry of the blue death: a case study in epidemiology and the history of science. Trautmann, N.M. (2009). Designing peer review for pedagogical success what can we learn from professional science?
2010	George, L. A., & Brenner, J. (2010). Increasing scientific literacy about global climate change through a laboratory-based feminist science course. Ghent, C. (2010). What undergraduates choose to think and write about when using internet. Sadler, T.D., & McKinney. (2010). Scientific research for undergraduate students: a review of the literature. Yang, Li-H. (2010). Toward a deeper understanding of student interest or lack of interest in science.
2011	Kolber, B, J. (2011). Extended problem-based learning improves scientific communication in senior biology students. Quitadamo, I. J., Kurtz, M. J., Cornell, C. N., Griffith, L., Hancock, J., & Egbert, B. (2011). Critical-Thinking grudge match: Biology vs. Chemistry—Examining factors that affect thinking skill in nonmajors science. Straits, W. J., Zwiep, S. G., & Wilke, R. R. (2011). Connecting students to science through structured reading of historical nonfiction.
2012	Clary, R. M., & Wandersee, J. H. (2012). Mandatory climate change discussions in online classrooms: Promoting students' climate literacy and understanding of the nature of science.

Koenig, K., Schen, M., Edwards, M, & Lei, B. (2012). Addressing STEM retention through a scientific thought and methods course.
Meyer, D. Z., & Meyer, A. A. (2012). Two paper airplane design challenges: customizing for different learning objectives.

Appendix 2: Example of excerpts from various *JCST* articles indicating NOS aspects

Aspects of NOS	Number of articles	Examples of excerpts
Tentative	8	"However, this does not approximate the process used by a scientist. Scientific discovery operates in a different manner. Facts are merely resting points until a new discovery is made, and science holds an interpretation of nature that is subject to alteration." (Tolman, D. A., 1999, p. 41)
Empirical	9	"Scientific knowledge is capable of public, empirical test. Its validity is established through repeated testing against accepted observations. Consistency among test results is a necessary but not sufficient condition for the validity of scientific knowledge." (Dunlop & Hodum, 2009, p. 68)
Inferential	5	"This case study is designed to help students understand how scientists can acquire knowledge from the fossil record, by using photos as examples of evidence (Dickey 2000). It is also an excellent example of an NOS case study that provides practice with testing hypotheses by making observations and drawing inferences and illustrates the tentativeness of conclusions." (Galluci, K, 2009, p. 52)
Methods of science	10	"I really learned that there is no one experiment or one way to gain scientific knowledge. When I hear the word *scientific*, I know it has to be tested, it has to be repeated. We have to back things up and constantly test your work. That's what nature of science is. Finding how it's all connected and related." (Dunlop, C. M., & Hodum, P., 2009, p.73)

Subjectivity	7	"Scientific evidence can be biased (i.e., distorted) in the way that data are interpreted, recorded, reported, or selected (p 207) …Scientists may, because of their background, personal beliefs, and values, emphasize different interpretations of evidence"(p 207) …In carrying out an investigation, no scientist must be made to feel that he or she should reach a particular result (p 207)…There appears to be a significant proportion of the students who view science and scientists as being objective and detached (p 208)…There is not generally an awareness of the social and cultural context of science." (Schibeci, R. A., & Murcia, K., 1999, p. 208)
Creativity	7	"In this study, we focused on four NOS aspects:…(4) how scientists can be creative (p. 19)…Denise, entered the course having a hard time thinking of science as a creative enterprise. Tables 2 and 3 present Denise's NOS understandings at the beginning and end of the wave unit. Through the reflective daily questions, Denise reconsidered the events that transpired in the course (specifically in its labs) and came to change her conception of how creative processes contribute to scientific knowledge: "At first I thought you just had to be smart to do science. You don't have to be creative to do an experiment" (Kattoula 2008, p. 167). Denise continued pursuing the issue of creativity in the wave unit as a result of answering the reflective daily questions guided by the pre-VNOS/ VOSI-PHYS instrument subscale." (Kattoula. E., Verma. G., & Martin-Hansen. L. 2009, p. 24)
Theory/ Law	1	"Students in this study developed more accurate ideas concerning the relationship between scientific theories and laws (i.e., theories and laws represent unique kinds of knowledge and theories should not be considered as underdeveloped laws)." (Sadler & McKinney, 2010, p. 45)

Sociocultural	7	“There is a rich blend of class discussions, field experiences, laboratory activities, long-term projects, in-class activities, and lectures.”Driving questions" that pay attention to not only science content, but also the nature of the socio cultural practice of science are used as a guide to organize the courses.” (Varelas, M., Plotnick, R., Wink, D., Fan, Q., & Y. Harris. 2008, p. 40)
Human endeavor	4	“Seen through this lens, science is a creative human endeavor that is influenced by society and culture, resulting in knowledge that is both tentative and subjective.” (Trautmann et al. 2003, p.445)
Other (Amoral, Communication)	4	“Some education research indicates that students are unlikely to learn about the nature of science simply by conducting their own experiments. Instead, explicit attention needs to be devoted to the role of research and communication in the construction of scientific knowledge (Abd-El-Khalick and Lederman 2000; Lawson 1999)…In response to a postsurvey question asking what students could learn about the nature of science by participating in this type of project, 40% of the 174 respondents mentioned learning about the world of professional science, including the importance of communication among scientists and publication of results.” (Trautmann, N.M., 2009, p. 16)
General	21	The course begins with an introduction to the nature of science (NOS), and class activities and journal readings provide students with the opportunity to discuss and reflect on multiple tenets of NOS. Students come to understand that scientific knowledge construction is a human endeavor that is based on empirical data. This knowledge is tentative and may involve elements of subjectivity, social negotiation, and creativity.” (Koenig, K., Schen, M., Edwards, M., & Lei, B., 2012, p. 25)

Appendix 3: Examples of elements of PCK from the articles occurring in the *JCST*

Element of PCK/ Description	Excerpts from articles
Knowledge of Science Curriculum • Mandated goals and objectives, what they identify as goal, what the authors have as their explicit goal. • What students have learned in previous years and what they will learn in later years (vertical curriculum) • Curricular programs and materials • Supplementary instructional materials	Dunlop and Hudson (2009) stated that their goal was to improve understandings of the nature of science in a laboratory course for prospective elementary teachers by creating a “scientist–science educator partnership” (p. 67)
Knowledge of students’ understanding of science • Requirements for learning- prerequisite skills and knowledge students need; developmental appropriate practices • Knowledge of areas of student difficulty; connections to common experiences, common errors, and misconceptions • Students think, say or do.	Gallucci (2009) clearly points out that when students in introductory biology class were taught nature of science aspects by using case studies, several students had difficulty in interpreting their observations in the proper context.
Knowledge of Assessment • Deciding what should be assessed in a particular learning experience • Methods of assessment (formative and summative)	Edcomb et al. (2008) assessesed both the prior knowledge of the education majors entering the integrated inquiry-oriented science course and their final gains after the class through a Likert-scale survey assessing “their confidence in their ability to teach science, their understanding of the nature of science, and gender stereotyped beliefs about science” (p. 24).

Knowledge of Instructional Strategies
• Subject-specific strategies for science (e.g., learning cycle)
• Topic-specific strategies:
   o Representations: illustrations, examples, models, and analogies
   o Activities: problem, demonstration, simulation, investigation, experiment, etc.
	‘New Society activity’ was used to introduce nature of science aspects in biology non-majors class (Cavallo, 2008).
	Historical case studies were used to understand history and process of science in introductory biology class (Susan, 2009).
	Student-driven investigation and project-based lab reports helped college students to understand scientific method and nature of science along with biology content knowledge (Lunsford, 2002).