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# A Self-Study of the Use of Concept Mapping to Assess NOS

**Dominike MERLE-JOHNSON[1], Nattida PROMYOD[2], Ya-Wen CHENG[3], Deborah HANUSCIN[4]**

**ABSTRACT**

We undertook a self study to examine and develop our pedagogical content knowledge for teaching the nature of science. We explored two different uses of concept mapping to assess preservice teachers' ideas about the nature of science (NOS) in an elementary science methods course. The class was divided into two groups. Group 1 was provided with aspects of NOS as starter concepts for their maps, while Group 2 was asked to develop their own concepts related to "science". We found that being given the NOS aspects constrained Group 1's ability to expand the connection of the main concept with other related words. On the other hand, Group 2 had difficulty moving beyond brainstorming related concepts. Based on this, we suggest that these two methods for concept mapping can be best used for different assessment purposes and at different points in NOS instruction.

**KEYWORDS:** Nature of science, pedagogical content knowledge, assessment, self-study, concept-mapping

# Bilimin Doğasını Değerlendirmek İçin Kavram Haritalarının Kullanımı Üzerine Bir Öz-İnceleme Çalışması

**ÖZET**

Bu çalışma bilimin doğasını öğretmek üzere kendi pedagojik alan bilgimizi incelediğimiz ve geliştirdiğimiz bir öz-inceleme (self-study)çalışmasıdır. Bu çalışmada bir ilköğretim fen öğretimi yöntemleri dersinde fen bilgisi öğretmen adaylarının bilimin doğası ile ilgili anlayışlarını değerlendirmek üzere kullanılan kavram haritalarının iki farklı kullanım şeklini keşfettik. Katılımcıları iki gruba ayırdık. 1. Gruba kavram haritalarını oluştururken bilimin doğasının yönlerini başlangıç noktası olarak almaları, 2. gruba isekendi "bilim" kavramlarını oluşturmaları söylendi. Çalışma sonunda bulgular 1. grupta yer alan katılımcılara verilen bilimin doğası yönlerinin bağlantıları kurmakta onların işini

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[1] Department of Learning, Teaching, & Curriculum, University of Missouri, E-mail: dmk99@mail.mizzou.edu
[2] Department of Teaching and Learning, University of Iowa, E-mail: nattida-promyod@uiowa.edu
[3] Department of Learning, Teaching, & Curriculum, University of Missouri, E-mail: yck86@mail.mizzou.edu
[4] Department of Learning, Teaching & Curriculum, University of Missouri, E-mail: hanuscind@missouri.edu

zorlaştırdığını gösterdi. Diğer yandan, 2. grup ilişkili kelimeleri bulmakta zorluk çekti. Bu bulgulara dayanarak her iki kavram haritası oluşturma yönteminin farklı değerlendirme amaçlarıyla kullanılabileceği ve bilimin doğası öğretiminin farklı aşamalarında işe yarar olduğunu söyleyebiliriz.

**ANAHTAR KELİMELER:** Bilimin doğası, pedagojik alan bilgisi, ölçme, öz-inceleme, kavram haritası

## INTRODUCTION

There is widespread agreement that students should not only learn the body of knowledge that constitutes science, but also how that knowledge was developed. Understanding of the values and assumptions that underlie scientific ideas, or the ‘nature of science’ (NOS) constitutes an important component of scientific literacy, and has been emphasized in numerous science education reforms around the world (AAAS, 1990; de Vos & Reiding, 1999; National Research Council, 1996). Despite these emphases, research has continually demonstrated that K-12 learners, as well as teachers, lack a full and robust understanding of NOS (Lederman, 2007). Much effort has been placed on identifying ways to ameliorate this problem. In particular, researchers have found instruction that explicitly addresses NOS to be more effective than instruction in which NOS is merely implicit within the learning activities. That is, NOS should be “… intentionally planned for, taught, and assessed” (Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001, p. 137). It is this later component of the explicit approach, assessment of NOS, with which we are concerned. Although there has been much debate among science educators as to the best way to assess understanding of NOS for research purposes (Chen, 2006; Elby & Hammer, 2001; Lederman, et al., 2002), classroom-based strategies for assessing learners’ understanding of NOS have received minimal attention. Recent work shows that though teachers may have well-developed knowledge of instructional strategies for teaching NOS, other aspect of their pedagogical content knowledge (PCK) for NOS, such as knowledge of assessment, may be less-developed (Hanuscin, Lee, & Akerson, 2010).

Teacher educators must be adequately prepared to support teachers in developing various aspects of PCK for NOS, and must have developed their own PCK for NOS in order to do so. Doctoral students, as future teacher educators, must similarly be prepared. Recent research, however, has called into question whether science education doctoral students are adequately prepared to help prospective teachers learn about NOS and how to teach it (Irez, 2006). As researchers, we have knowledge and experience using various assessment tools and instruments to examine learners’ conceptions of NOS; however, as prospective teacher educators, we realized that we lacked a parallel repertoire of classroom-based assessment strategies to enact when teaching about NOS. Thus, we were interested in developing our own knowledge of how to assess NOS in the context of classroom instruction, so that we might better assist prospective teachers in undertaking assessment of NOS. Here we describe a self study in which we utilized concept maps, a common assessment tool, to understand our students' ideas about NOS and to further develop our own PCK for NOS.

## TEACHING AND ASSESSING NOS

Abd-El-Khalick and Lederman (2000) stress that in addition to adequate understanding of NOS, to teach NOS effectively, teachers must have:

> …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 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)

In other words, they need *pedagogical content knowledge* for NOS. Shulman (1987) first introduced the notion of pedagogical content knowledge (PCK) as a fundamental component of the knowledge base for teaching. PCK, according to Shulman, is what makes possible the transformation of disciplinary content into forms that are accessible 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 and presented for instruction (Magnusson, Krajcik, & Borko, 1999). Magnusson et al.'s model of PCK includes five components: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum (goals & objectives/ curriculum and materials), (c) knowledge and beliefs about students' understanding of specific science topics (prerequisite knowledge and student misconceptions), (d) knowledge and beliefs about assessment in science (dimensions of science learning to assess and knowledge of methods of assessment), (e) knowledge and beliefs about instructional strategies for teaching science (topic-specific activities, e.g., NOS; as well as subject-specific strategies, e.g., inquiry).

Though much effort has been directed toward improving teachers' instructional strategies for teaching NOS, little emphasis has been given to other components of teachers' PCK for NOS such as knowledge and skills for assessing of NOS. Current descriptions of teachers' assessment practices related to NOS are at best vague. Several studies that have considered teachers' assessment of NOS (though not as a central focus of the research) reveal that teachers do not formally assess students' ideas about NOS (Abd-El-Khalick, Bell, & Lederman, 1998). Rather, teachers may use informal strategies such as questioning (Schwartz & Lederman, 2002) and base their evaluations of the effectiveness of their instruction on intuition about how the lesson 'worked' with students (Bartholomew et al., 2004). The few teachers reported to formally assess NOS have done so through more traditional means. For example, Lederman and colleagues note that to assess his students, a teacher wrote "two exam questions aligned with his two objectives on scientific models (inference) and tentativeness" (2001, p. 152). Similarly, Bartholomew and colleagues (2004) cited teachers' intentions (though not carried out) to test students' understanding of the words "observation" and "inference".

In the literature on teaching prospective teachers about NOS, there is similarly little information about classroom-based assessment tools teacher educators utilize to examine their students' ideas about NOS. Spector, Strong & La Porta (1998) report the use of concept maps as one of the tools to assess pre-service teachers understandings of NOS in a Science-Technology-Society course for pre-service teachers. Preservice teachers constructed individual concept maps as an out of class assignment before the course instructor formally introduced NOS; then following five lecture-discussion sessions about NOS, they constructed concept maps as cooperative groups. The instructors then initiated discussions about concept map similarities and differences, as well as why some concepts were linked to other in a specific way.

Others have utilized concept maps for research purposes in studying learners' ideas about NOS. For example, in a recent study researchers used two tools, concept maps and VNOS (Lederman et al., 2002), to assess the preservice teachers' view on NOS (Borda et al., 2009). All of the participants in the study did selected items from VNOS-C and developed concept maps with small groups before and after instruction. The authors argued that concept maps provided information about students' prior and current knowledge and the structure of their understanding of NOS (Borda et al., 2009). Similarly, Irez (2006) assessed science teachers' understanding of NOS using concept maps, and found they assisted the researchers in understanding the strengths and weaknesses of teachers' understanding of NOS. Although the concept maps used in Borda's and Irez's work were utilized for research purposes, concept maps are a viable assessment tool in a classroom in terms of evaluating students' understanding of NOS.

### *Concept Mapping*

Concept mapping is an assessment tool that has been shown to be helpful in promoting students' critical thinking, creativity, organization, and summarization skills (Novak & Gowin, 1984). In a concept map, a set of concepts are connected to the main idea(s) in a two dimensional form by a series of nodes, links and sometimes cross links, which form propositions that represent how the individual visualized the relationship among concepts (Novak, 1998; Novak & Gowin, 1984). For example, a concept node labeled "science" can be connected to a concept node "theories" using the linking words "can result in" to form the proposition "science can result in theories." As an assessment tool, concept maps can be used by teachers to evaluate students' ideas on how much understanding their children get from the lesson, or whether or not they can connect their own knowledge structures. As a result, concept maps would help teachers improve or adjust their teaching to fill the students' deficiencies of understanding.

Because of the unique features of concept mapping, concept maps could be used in different ways to serve different assessment purposes. Hodson (1992) suggested four types of assessment to use in the science classroom to assess learning and teaching. Hodson's assessments include formative, summative, evaluative and educative assessments. As a formative assessment tool, concept maps can allow the teacher identify gaps in student understanding, alternative conceptions and preconceptions students hold. As summative assessment tool, concept maps can be used by teachers to evaluate students' growth in learning following instruction. For example, Novak and Gowin (1984) describe methods for grading student concept maps. Concept maps can also offer teachers opportunities to identify needed modifications to their curriculum based on students' learning outcomes, thus serving an evaluative purpose. Finally, because concept maps enable students to link new and prior knowledge and make meaningful connections, they may also serve an educative purpose.

## AIM OF THE STUDY

Realizing we lacked sufficient knowledge of assessment for NOS, we were interested in answering the question, *How can concept maps be used as a classroom assessment tool in regard to NOS?* and to further develop our PCK for NOS. Currently, there are few concrete examples of PCK in the literature (Loughran, Berry & Mulhall, 2004) and little research that has specifically applied PCK as a framework to understanding the teaching of NOS (Lederman, 2007). In the current study, we address this gap by building up a robust portrayal of our PCK for NOS, as well as articulating how our PCK is enacted in our practice. To accomplish this, we relied on self-study (Loughran, 2007), a method that draws from and builds upon the traditions of reflective practice, action research, and practitioner research.

## METHOD

According to LaBoskey (2004), self-study is (a) improvement-aimed; that is, it involves evaluating practice and reframing thinking; (2) interactive; in that it involves engaging with colleagues, students, the literature, and one's previous work to confirm and challenge one's thinking; (3) reliant on multiple, primarily qualitative data sources; and (4) revolves around a need to formalize one's work and make it available to the professional community. As a form of case study, the results of self-study are not intended to be generalized across populations.

Nonetheless, this form of inquiry provides in-depth descriptions that illuminate the complexities of teaching and articulate the "wisdom of practice" (Shulman, 2004); consistent with PCK as a theoretical framework. Self-study not only helps those engaged in this type of scholarly activity address problems in their own immediate teaching contexts, but can produce knowledge that "teacher educators in other settings can draw on and adapt to their own teacher education settings" (Dinkelman, 2003, p. 11). We conducted this collaboratively, with the guidance of a faculty member experienced in teaching NOS (fourth author).

To examine our PCK, we utilized the Content Representation tool, or CoRe and constructed narratives to conceptualize our PCK through Pedagogical and Professional-experience Repertoires (PaP-eRs) (Loughran et al., 2006). A CoRe consists of a matrix that outlines important aspects of teaching and learning of specific science content. It addresses what teachers intend students to learn and why it is important, difficulties/limitations connected with teaching the content, knowledge of student thinking and particular ways to ascertain student understanding, and specific teaching procedures and reasons for using them. As Loughran et al. (2006) note:

> …working on a CoRe creates a sense of professional learning and sharing of the expertise of teaching that, for many teachers, is considerably different from what they have previously experienced. In discussing, debating, and articulating [their ideas] teachers quickly develop ways of discussing their practice that make that which is normally implicit, private and individual, explicit, clear and meaningful for themselves and their colleagues (p. 25).

A PaP-eR is a "narrative account of a teachers' PCK that highlights a particular piece, or aspect, of science content to be taught" and "is designed purposefully to unpack a teachers' thinking about a particular aspect of PCK" (Loughran et al., 2006, p.24).

We first constructed a CoRe related to our ideas about teaching NOS; this was subsequently added to and revised as further insights were gained and our thinking was clarified and refined (Loughran et al., 2006). As stated previously, one particular way of ascertaining students' ideas about NOS that we identified was concept mapping. While we had experience applying this assessment tool to other topics, we had not utilized this specifically in regard to NOS. With the guidance of our faculty mentor, we brought our idea of concept mapping into her elementary science methods course for pre-service teachers. In the next section, we illustrate how this experience shaped our PCK for NOS through a series of narrative Pa-PeRs. The CoRe is both a research tool for accessing understanding of a particular content (in this case PCK) as well as a way of representing that knowledge; similarly, the PaP-eRs help illustrate PCK in action (Loughran et al., 2004). Taken they form a Resource Folio that reveals the complexity and interplay of our PCK for NOS.

## FINDINGS

We present our findings and portray our PCK for NOS through presentation of a CoRe for NOS (see Appendix) and a series of Pa-PeRs, each of which is intended to make salient a different aspect of our knowledge for assessing NOS, as developed through this self-study.

### Pa-PeR 1: Why concept mapping to assess NOS?

*In this Pa-PeR, the authors reflect on the rationale for concept mapping as an assessment tool for NOS. The Pa-PeR takes the form of a conversation among the authors about their practice.*

Ya-Wen: I think that in addition to "traditional" assessments, like tests and quizzes, there must be a fun and easy-to-use tool to assess students' ideas about NOS. Personally, I do not like paper and pencil tests because I always think I know better than my scores tell me. And, I always feel nervous and uncomfortable taking traditional assessments. I think concept mapping is a fun and easy tool to use in learning. In order to develop concept map, I have to know the concepts and the connection between key concepts. It makes me think deeply. Furthermore, concept maps help me organize and visualize my thoughts and ideas. As an international student, concept maps are also is a useful communication tools in group discussions and presentations. I can clearly explain what I learn and it's easy to indentify my misunderstandings.

Dominike: I agree with Ya Wen. Concept mapping can be used as a seamless assessment (i.e., embedded in the lesson) and in that way, students do not have to feel threatened as they may feel when taking exams or other types of assessments. Concept mapping can serve as a tool to open discussions, and it's an assessment in which the students can go over and over it as many times as the teacher or they want, and it can be changed as more knowledge is acquired and more misconceptions are targeted. My experiences using concept mapping with students have shown that at the end, students appreciate this assessment strategy because looking at the connections they made among concepts through time, they could see the gaps in their own understanding and reflect upon how that understanding has changed.

Nattida: I also agree students might feel uncomfortable taking a paper and pencil test since it makes <u>me</u> nervous. Additionally, students may get caught up on memorization if they are preparing for a test. With concept mapping, students have to go beyond that. To me, concept map is very great tool for students to use in order to make their thought visible. As to the point of second language learners Ya-Wen raised, I believe that many international students have a high ability in learning, but due to language barriers, they don't represent or communicate what they think well. So, concept mapping is a solution. However, concept maps are not useful just for an international student, but for all learners. It can be used as a tool to do both formative and summative assessment, which is useful for both teachers to assess their teaching as well as for students to evaluate their understanding.

Dominike: Yes! Concept maps are a good formative assessment in the sense that the students not only provide concepts that they know, but they also provide links they see and the description of each of the links (as linking words), which the teacher can examine to assess whether the students understand the connections between concepts. NOS aspects are linked to each other, and this is a good reason why concept maps are a good assessment tool for NOS understanding.

Ya-Wen: In order to construct a concept map, students have to link concepts together. In this way, concept maps allow teachers to view their students' understanding of NOS aspects, but also to understand the connections they make between different aspects of NOS. After all, understanding NOS is more than just being able to define the various aspects individually; it is being able to see the bigger picture of science.

Nattida: I also believe using concept mapping is a good summative assessment tool because the students can create one concept map before, then another one after learning about NOS in class, and by looking at the first one, they can reflect upon their learning, like Dominike suggested. The teacher can reflect, too, upon his/her teaching of NOS and see whether students made more connections.

**Pa-PeR 2: In the Classroom**

*In this Pa-PeR, the authors describe their implementation of concept mapping in an elementary science methods course, and reflect on their ideas about what occurred.*

To find out how concept mapping can help teachers to assess what students know about what science is, we brought our idea of concept mapping into an elementary methods course for pre-service teachers. Since we did not know if the all or any of the students were familiar with concept maps we began the activity by asking the pre service teachers *what is concept mapping*? and we had those familiar with the strategy share their experiences.

| **What happened?** | **Our thinking** |
|---|---|
| Both groups immediately began the task without hesitation and all members were actively participating. | Students understood their task. Concept mapping seems to be an effective assessment tool to engage the students into their learning and understanding- this supports our reason for using it as a 'seamless' part of the learning activities. |
| Group 1 immediately started to construct their map and identify connections between concepts; Group 2 spent a majority of time brainstorming, and had difficulty beginning to build their map by connecting concepts. | It seems like the method we used for Group 1 is more suited for helping students focus on connections between ideas. Group's 2 method still seemed to engage them, however, even though they weren't making connections yet—they were brainstorming diverse concepts related to their ideas about science. |
| Group 2 brainstormed a variety of concepts, only some of which were directly related to NOS—rather, many of their concepts were quite broad and included topics within the domain of science (e.g., ocean). | Maybe we should have given more restricted rules. For example, we could have told them to just brainstorm a certain (few) amount of concepts, so they could begin to focus on the connections. Or maybe we could have given the concept "Nature of Science" instead of just "science", and they would have focused more on NOS aspects they had learned and the connections among concepts. |
| Group 1 hesitated in identifying additional words to include with their concept map, and only did so with our encouragement. | In this case, we could have asked them to do the opposite of Group 2, or ask them to think of other concepts associated with science, instead on focusing just on the NOS concepts provided. Being given the NOS concepts could have constrained their thinking. Perhaps there are other things they would associate with besides what we provided. |
| At one point, we intervened with Group 2 to ask them to start constructing the links and linking words. | Students shouldn't be left to flounder on building their concept maps; sometimes it's important for the teacher to give additional instructions that can help students move forward in the process. Deciding *when* is the appropriate time to do that is tricky; for us, it happened when we noticed that they had many concepts to work with and few connections built. |

Second, we gave a definition of what a concept map is, based on Novak and Gowin (1984). Then we talked about the different concept map parts (e.g., concepts, links, linking words, cross-links). Fourth, we provided the pre service teachers with two different concepts maps as examples for them to compare which one gives a better idea of a students' knowledge of a concept. Fifth and last, we asked them to construct a very simple concept map about a science concept with which they were familiar (plants).

Once we believed they had a general sense of how to construct a concept map, we divided the class into two big groups:

- Group 1 was divided into 4 subgroups of 2-3 members. The task was that each subgroup had to develop a concept map given the main concept (science) along with NOS aspects such as: subject to change, creativity and imagination, scientific method, and bias. We asked them to organize the concept map with appropriate links, linking words, cross-links and examples; we also gave them empty cards and let them add other words related to "science" other than the words we gave.

- Group 2 was also divided into 4 subgroups of 2-3 members. However, group 2 had to come up with the concepts associated with the main concept by themselves. They brainstormed the concept as a whole group and then developed their concept maps with linking words, etc.

We decided to use these two different methods based on the experience of the first author of this implementing concept mapping in an undergraduate science content course.

**Pa-PeR 3: What do the maps show?**

*In this Pa-PeR the authors analyze the concept maps created by the two instructional groups and what they reveal about student thinking. Below are two example maps created by students in Group 1 and Group 2.*

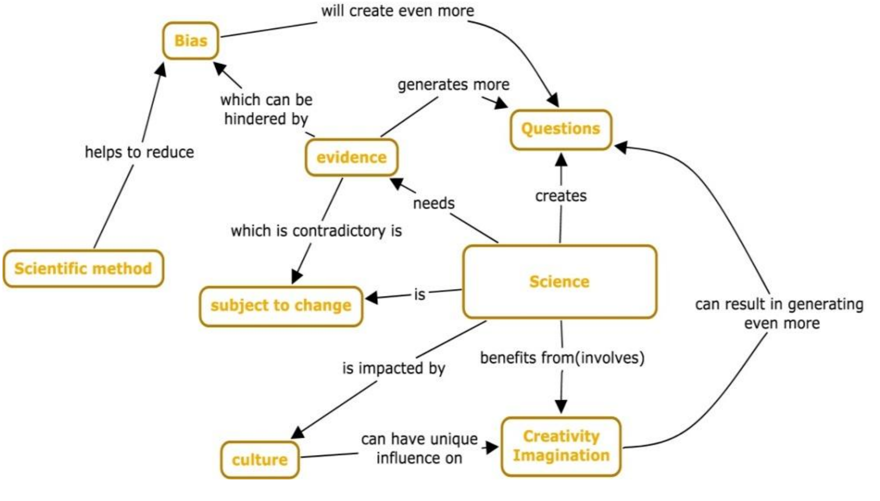


*Figure 1.* Concept map created by group 1 (NOS aspect provided)

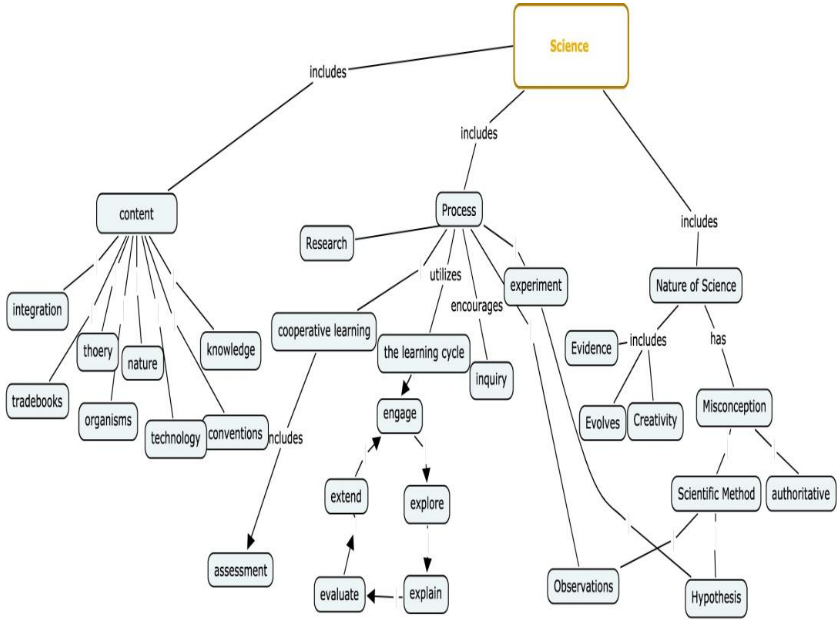


*Figure 2.* Concept map created by group 2 (Only main concept provided)

In terms of what we learned from the concept maps created, we saw that most of the times, concept maps created by Group 1 had linking words included whereas most of Group 2 concept maps do not have or have very few linking words. We attribute this phenomenon to two reasons: 1) Group 1 were given the NOS aspects, so they had guidance as to what we wanted them to focus the concept map on, and 2) Group 2 brainstormed so many different concepts associated with science that they did not had enough time to write or think about the linking words between all those concepts. In other words, they lacked focus. One Group 2 added the concept nature of science and included it at the top of the concept map below science, meaning that nature of science is the theme that links the main concept "science" and the other concepts provided. On the other hand, this group did not create a linking word for "scientific method" and "subject to change" possibly meaning that they were not able to come up with a word that expresses this relationship. As teachers, these connections of concepts and linking words can help us see any misconceptions students can have and/or any lack of knowledge on the relationship of the concepts. By finding that students don't know how to relate concepts, even though that they are aware of a relationship between them, we can start a class discussion that helps the students build the relationship of the concepts. Group 2 reflected that they can come up with many concepts associated with what science is. They were able to offer NOS aspects and relationships of those aspects by showing a lot of links and linking words between most of the concepts created. Since their instructions were open to any concepts they can think of related to science, they included some NOS aspects, some areas of science (i.e., evolution), science process (i.e., experiments), some specific examples of what science studies (i.e., poison dart frog), and even some (i.e., supernatural). Overall, this approach was more open ended, giving the students the opportunity to write all they can think, and related to the main concept in the time frame provided.

As we look at the two concept maps in detail, we are able to see aspects of NOS that students grasp, and also areas that would require further instruction. In addition, we can also catch students' confusion. For example, from Figure 1, which shows a concept map in which students had some NOS aspects provided, it's clear that they were able to identify relationships between these aspects. We can read that students think that science needs to be supported by evidence; however, the evidence can be hindered by bias, and the bias can be reduced by scientific method. It would be important for us to probe more deeply what students mean by "scientific method". This group also stated that "culture can have unique influence on creativity and imagination", showing that they grasp the sociocultural influences on science. In looking at Figure 2, which was a map created by students provided only the main concept "science", we can see that students associated particular ideas with each other, but did not make specific connections and identify relationships. For example, "science includes process", which is then linked to research, corporative learning, learning cycle, inquiry, and experiment. So, from their map, we know that these things are associated with science processes in their thoughts. In this case, the teacher can check whether the students did not make these connections because of lack of time or because they did not know the relationship about the concepts. This may also indicate they are thinking along the lines of science being a *class which they will teach* versus thinking of the broader scientific enterprise.

**Pa-PeR 4: Which method is best?**

*In this Pa-PeR the authors recall their debriefing session following using concept maps with preservice teachers in which they discussed how they could use each method for concept mapping and when during instruction different methods of concept mapping should be used.*

After the groups developed and shared their concept maps, we asked students to observe what the other groups had done and to think about similarities, differences and other characteristics of the maps they noticed. In the wrap-up, the students (as well as we) realized that group 1 concentrated more on building the relationships between the given concepts. One of the members of group 1 commented that after her group built the relationships between the given concepts, they had a hard time thinking of new words to link. Many other members of Group 1 agreed with her. Another Group 1 member said that Group 1 words could fill out gaps or links they have between the words that were given to them. The whole group discussion, from the perspective of *teaching*, led to two big ideas: 1) that the method we used to assess group one's knowledge of what science is would be better to use *after* we have explicitly taught about NOS, and 2) whereas group's 2 method was more useful to assess students' prior knowledge of what science is *before* explicitly discussing nature of science. In other words, the prospective teachers themselves recognized concept mapping could be used both formatively and summatively assess students' ideas about science.

There are both advantages and disadvantages to using concept mapping as an activity to help students develop ideas about nature of science. If we limit the words for students when doing a concept map, it may constrain their ideas and creativity. On the other hand, if we let them create their own words, it might be difficult to complete the concept map in time because they would focus on just thinking about words and not pay attention to considering how those relate. Moreover, they might think out of the conceptual frame we expect them to. Although both methods showed some limitations, we found that we can utilize these two different approaches in order to achieve different purposes. Giving words to the students can help the students test their skills in connecting concepts, whereas letting them come up with words or concepts by themselves can help them assess their prior knowledge about the main or related concepts that they remember from their learning.

Teachers can use the method implemented for Group 1 to assess students' new understanding of what science is following instruction. The terms, linking words, links and cross links the students develop can be used to help find out any alternative conceptions students have and plan the next steps of instruction. Prior to explicit NOS instruction, teachers can use the method we implemented for Group 2. Students create their own concepts of what science is for them and the teacher could see how to introduce NOS to students in a way that builds upon students' existing ideas. Teachers can ask the students to do concept maps in groups to help students think aloud and discuss ideas with classmates. This provides an additional level of engagement and discourse.

## DISCUSSION and IMPLICATIONS

Using self-study as a framework to support our PCK development has helped us evaluate and reflect upon the use of concept mapping in regard to NOS. As Loughran et al. (2006) emphasize, PCK is not simply using a teaching procedure because it 'works; 'rather, the expert teacher chooses particular teaching procedures for particular reasons. In this case, our choice of concept mapping as an assessment tool was largely linked to our view of NOS as being more than understanding any particular aspect in itself, but rather in the connections learners make among these aspects. The power in this assessment lies in its utility in making those connections apparent to the instructor as he/she seeks to understand learners' ideas. Thus, concept mapping is consistent with the goal of helping learners connect their ideas about NOS into a coherent, overarching

framework. Furthermore, we note that collaboratively constructing a concept map provides opportunities for discourse among learners. In this manner, it has the potential to foster the forming of connections between different aspects of NOS as students negotiate and debate options for constructing the map.
As illustrated by the Resource Folio, we developed a better sense of when it would be appropriate to use different concept mapping methods at different points in instruction. We have a more robust sense of how this tool might be utilized for both formative and summative assessment of learners' ideas about NOS. Namely, that more open-ended methods (e.g., providing the main concept only) may initially provide information about what ideas learners associate with NOS, while more constrained methods (e.g., providing a set of concepts) allow the instructor to obtain more detailed information about connections students make between specific aspects of NOS. In other words, like Lacy and Hanuscin (2010), we found our choice of assessment strategy for NOS largely influences the type of responses we received.

Our *knowledge of assessment* of NOS was deepened, in that we were able to identify an appropriate assessment tool for NOS, but also explore variations in approaches to using this tool and develop an understanding of the advantages and disadvantages of each. In addition to developing our knowledge of assessment, however, we find we have also developed other aspects of our PCK for NOS through this process. For example, through our use of concept maps, we became more aware of preservice teachers' ideas about NOS, including their misconceptions, and areas of difficulty they had in making connections between various NOS aspects. In this manner, we further developed our *knowledge of learners.*

Classroom experience itself is no guarantee of PCK development (Tobin & Garnett, 1988). The willingness to improve and reflect is key to developing PCK (Tuan, Jeng, Whang, & Kaou, 1995) as is a supportive working atmosphere in which collaboration is encouraged (Kind, 2009). For us, self-study provided a mechanism through which we might use our experience implementing concept mapping to reflect on and improve our knowledge for assessing of NOS, and in turn develop our PCK for NOS. Loughran (2007) described self-study as a "methodology for educators to help them aligned their teaching intents with their teaching actions" (p. 12). The collaborative nature of the process allowed us to make explicit our beliefs and intentions and to reflect on our teaching in light of those.

Our work supports the notion that self-study provides a fruitful means through which prospective teacher educators, under the mentorship of a faculty member, might address specific gaps in their PCK. Furthermore, our findings illustrate how concept mapping can be a viable classroom-based assessment tool for exploring learners' understanding of NOS.

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# APPENDIX

| | Empirical NOS | Creative NOS | Subjective NOS | Tentative NOS | Methods of Science | Sociocultural NOS |
|---|---|---|---|---|---|---|
| What do you intend students to learn about this idea? | Scientific claims must be based on evidence | Creativity is a vital part of scientific work. | Science depends on our current state of knowledge, our beliefs, and assumptions. | Scientific ideas can change based on new evidence or new ways of looking at the evidence. | There is no one universal "scientific method" used by all scientists. | Science and culture influence one another. |
| Why is it important for students to know this? | Students should be prepared to evaluate claims and distinguish between science and pseudoscience | Students are often turned off by the view of science as being strict, rigid, and procedural—they can enjoy science more when they see how they can use creativity to do science | Students are quick to believe anything labeled "scientific"—and so this can help them be skeptical of the motives and underlying assumptions of scientific work | Students shouldn't mistrust science because one day eggs are good for you and another day they're not—they need to understand how this is a normal part of science, and a strength of science | Students should understand and appreciate the diversity of scientific work and the diverse ways in which scientists make sense of the world. | Science is best understood in the context of society; society influences the direction of scientific work and vice versa. |
| What else do you know about this idea (that you don't intend students to know yet)? | We know from our coursework on NOS that philosophers, historians, and sociologists all have different ways of viewing science. For example, Kuhn viewed changes in science as 'revolutions' in which one paradigm replaced another. | | | | | |

*Appendix (continued)*

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| Difficulties/ limitations connected with teaching this idea. | Traditional forms of instruction may encourage knowledge by authority. | Creativity is usually associated with artistic talent vs. creating of ideas and concepts | We use "subjective" in everyday life with a negative connotation (bias, dishonesty) | When science changes, students may think this is because science was 'wrong' | Teachers traditionally call ALL science activities 'experiments', so students may not differentiate this term. "THE Scientific Method" is entrenched in schools. | Sometimes cultural norms and values are not easily visible to members of that culture |
| Knowledge about students' thinking which influences your teaching of this idea. | Students may not discriminate on the quality of data used in making a claim.<br><br>Students may have difficulty themselves in making claims based on evidence. | Students may misperceive science as being procedural and "cut and dry". | Students think that science is objective (but we're all human, even scientists) | Students may think that science "proves" things beyond the shadow of a doubt. | Students may give priority to "experiments" and not realize observations, collecting specimens, doing theoretical work, etc. are all part of science. | |
| Other factors that influence your teaching of this idea. | Finding opportunities to make NOS an explicit part of the classroom discourse is important; however, it can easily fall by the wayside given time constraints. NOS can't be an add-on, it has to be an integral part of the curriculum. | | | | | |

*Appendix (continued)*

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| Teaching procedures (and particular reasons for using these) | Teaching about the nature of science (NOS) requires explicit instruction in which students are introduced to ideas about NOS, are able to identify examples from historical or contemporary science that illustrate those aspects, and to reflect on their own ideas about science in light of that. Teaching procedures that are content-generic (e.g., tricky tracks, the Tube, the Great Fossil Find, New Society, etc.) can be useful for helping students get to know what is meant by "tentative" or "subjective" initially. Whereas, inquiry provides an opportunity for students to draw parallels between their work and the work of scientists. Content-embedded activities provide evidence to students about how science works. For example, examination of studies in astronomy can illustrate that not all scientists do experiments in which variables are manipulated. |
| Specific ways to ascertain student understanding or confusion (include likely range of responses) | Questioning students during discussions can be an informal assessment strategy.<br>Concept maps can illustrate students' connections (or lack of) between aspects of NOS. |