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National Board Certification (NBC) as a Catalyst for Teachers' Learning about Teaching: The Effects of the NBC Process on Candidate Teachers' PCK Development

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Abstract: This study examined how the National Board Certification (NBC) process, especially the portfolio creation, influenced candidate teachers' pedagogical content knowledge (PCK). In a larger sense, this study aimed to construct a better understanding of how teachers develop PCK and to establish ecological validity of the National Board assessments. Qualitative research methods, most notably case study, were utilized. Participants were three high school science teachers who were going thorough the NBC process. Data sources included classroom observations, interviews, teachers' reflections, and researcher's field notes. Data were analyzed using the constant comparative method and enumerative approach. Findings indicated that the NBC process affected five aspects of the candidate teachers' instructional practices that were closely related to PCK development: (a) reflection on teaching practices, (b) implementation of new and/or innovative teaching strategies, (c) inquiry-oriented instruction, (d) assessments of students' learning, and (e) understanding of students. © 2008 Wiley Periodicals, Inc. J Res Sci Teach 45: 812–834, 2008
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Pedagogical content knowledge (PCK) is a type of knowledge specifically possessed by expert teachers. The name makes a conjunction between subject matter content and pedagogy, with the suggestion that this amalgam represents the understanding necessary for transforming subject matter into forms that are more accessible to students (Shulman, 1986, 1987). Teachers who possess this knowledge might, for instance, be able to delineate what is easy or difficult for students to learn, and/or how to organize, sequence, and present the content to accommodate the diverse interests and abilities of the students (Carter, 1990). Because PCK is specific to the teaching of particular topics and thus developed through an integrative process rooted in classroom practice (Van Driel, Beijaard, & Verloop, 2001), it represents knowledge that is ''uniquely the province of teachers, their own special form of professional understanding'' (Shulman, 1987, p. 8). Consistent with this, Cochran (1992) asserted that PCK is the ''knowledge that makes science teachers teachers rather than scientists'' (p. 4).

In a study to elaborate the knowledge bases of teaching, Grossman (1990) suggested that possession of the knowledge described within PCK was anticipated as having the greatest impact on teachers' classroom actions. The validity of her assertion was supported by the numerous lines of research on teaching that showed the importance of PCK in teachers' planning and actions when dealing with subject matter (Clermont, Krajcik, & Borko, 1993; Van Driel, Verloop, & De Vos, 1998), teachers' learning of new instructional strategies (Borko & Putnam, 1996; Smith & Neale, 1989), and student learning (Carpenter, Fennema, Peterson, & Carey, 1988). Thus, it follows that PCK is a critical element for effective teaching of a subject.

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Because of this importance, PCK needs to be elevated to a stature such that it is used as a means of identifying and understanding teaching expertise just as much as subject matter knowledge and pedagogical knowledge (Shulman, 1987).

In fact, PCK has been described as a knowledge base necessary for effective teaching in many educational reform documents (e.g., American Association for the Advancement of Science [AAAS, 1993]; National Research Council [NRC, 1996]). The National Board for Professional Teaching Standards (NBPTS) also stresses the importance of PCK within their five core propositions as a crucial element of what teachers should know and be able to do (NBPTS, 2004).

NBPTS, however, moved beyond the other reform efforts. To recognize and reward outstanding teaching, NBPTS has developed a certification that is accomplished through the completion of performance-based assessments consisting of portfolio entries and assessment center exercises. A candidate's efforts to achieve NBC during her or his initial attempt are likely to take the better part of a school year and involve a total of 200–400 hours of work (NBPTS, 2004).

By reviewing literature on the reliability of National Board assessment, Porter, Youngs, and Odden (1996) concluded that the National Board assessments can be legitimately used to distinguish between accomplished teachers and other teachers. They further argued that the NBPTS emphasized the need of teachers to have PCK, knowledge of students, reflective practice, and the ability to engage students in active learning. Another study that compared the teaching practices of National Board Certified teachers (NBCTs) with those of other teachers indicated that NBCTs have more sophisticated PCK than other teachers (Bond, Smith, Baker, & Hattie, 2000). Those findings, however, cannot provide understanding of whether NBCTs already had sophisticated PCK and then demonstrate this knowledge through the process or whether they also develop their PCK while going through the process. If teachers advance their knowledge through the process, NBC can be recognized as a form of professional development as well as reward. With this in mind, this study proceeded from the following research question: how does the NBC process, in particular the portfolio creation process, influence the development of candidate teachers' PCK?

The purpose was twofold. This study aimed to obtain a better understanding of how experienced teachers continue to develop their knowledge for teaching. This aspect of the purpose was sought through an investigation of teachers' PCK development in the context of the NBC process. The other purpose was to contribute to understanding the value of NBC. In particular, this study intended to examine the ecological validity (Kagan, 1990) of the National Board assessments. Ecological validity, in this context, refers to the outcome that results from the analysis of evidence concerning the relevance of an assessment technique to classroom life (Kagan, 1990). Stated another way, our examination of this instance of ecological validity included the examination of concerns regarding whether teachers' performances, as measured by a particular tool or task, are related to specific classroom behaviors and/or to valued student outcomes. PCK must have referents within what teachers know about their subject matter and how they translate this subject matter knowledge into instructional or curricular events (Carter, 1990). Accordingly, PCK can be expressed only when teachers deal with the transformation of subject matter for a specific group of students in a specific classroom, and in this regard it is closely linked to teachers' actual teaching performances and student learning. Hence, by investigating teachers' PCK development through the NBC process, it is possible to investigate ecological validity of NBC.

Theoretical Background

Pedagogical Content Knowledge

The term, pedagogical content knowledge, originated with Shulman's 1985 presidential address to the American Educational Research Association. Shulman (1986) defined PCK as a particular form of content knowledge that ''goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge *for teaching*'' [emphasis in original] (p. 9). In a later article, Shulman (1987) included PCK in what he called ''the knowledge base of teaching,'' stating that PCK is of special interest because ''it identifies the distinctive bodies of knowledge for teaching'' (p. 8). Accordingly, PCK has been regarded as a particular body of knowledge that distinguishes those who are expert subject matter ''teachers' from expert subject matter 'knowers'" (Berliner, 1986, pp. 9–10).

Since the inception of PCK, a large and apparently growing number of scholars have worked on the concept (e.g., Cochran, DeRuiter, & King, 1993; Geddis, Onslow, Beynon, & Oesch, 1993; Grossman, 1990; Loughran, Gunston, Berry, Milroy, & Mulhall, 2000; Magnusson, Krajcik, & Borko, 1999; Marks, 1990; Wilson, Shulman, & Richert, 1987). However, the concept of PCK has been interpreted in various ways according to different scholars and research agendas (Loughran et al., 2000; Park, 2005). Although some authors have chosen to define PCK in terms of the accumulation and awareness of subject matter specific activities for teaching, other researchers have identified PCK as knowledge about pedagogy possessed of a high level of specificity with respect to the characteristics of the students being taught, the subject matter, and classroom contexts (Cochran et al., 1993). In addition, some emphasize the generic nature of PCK (e.g., Fernandez-Balboa & Stiehl, 1995), whereas others underscore the topic-specificity of PCK (e.g., Van Driel et al., 1998). All of these issues has made defining PCK more challenging.

Given that there is no agreed-upon definition of PCK, we first used a comprehensive literature review as a means to recognize the range of components included in the various operating definitions of PCK. As a result, we identified five major components constituting PCK and defined PCK as an integration of those components. The five components were drawn particularly from the work of Grossman (1990), Tamir (1988), and Magnusson et al. (1999). The components are as follows: (a) orientations to science teaching, (b) knowledge of students' understanding in science, (c) knowledge of science curriculum, (d) knowledge of instructional strategies and representations for teaching science, and (e) knowledge of assessments of science learning (see Park, 2005, for descriptions of the five components).

For a teacher to enact effective teaching, she or he needs to integrate the components of PCK and apply them in a specific classroom, with a certain set of students, in the context of that moment (Fernandez-Balboa & Stiehl, 1995). This integration is accomplished through the complementary and ongoing readjustment by both reflection-in-action and reflection-on-action, resulting in strengthened coherence among the components (Park & Oliver, in press). To emphasize the interrelatedness and integration among the components and the critical role of reflection, we represented these components in a pentagonal form as shown in Figure 1. This model suggests that the development of one component within PCK will, in turn, influence the development of others, and ultimately enhance this holistic PCK. Because PCK, which comprises effective teaching, requires the integration of the components in highly complex ways, lack of coherence among components can be problematic in developing PCK and increased knowledge of a single component may not be sufficient to stimulate significant change in practice. In the present study, this model served as a conceptual tool for data analysis and interpretation.

National Board for Professional Teaching Standards Assessments

The National Board for Professional Teaching Standards (NBPTS) was established in 1987, and is supported by the U.S. Department of Education and private funding. Its mission is to operate a national voluntary system to assess and certify teachers who measure up to its rigorous standards of teaching performance. The NBPTS has developed performance-based assessments designed to appraise not only the knowledge teachers possess, but also the actual demonstration of their skills and professional judgment as applied daily in the classroom (NBPTS, 2004). These assessments consist of portfolios and assessment center exercises. During the past decade, the NBPTS developed 27 areas of certification and has awarded certificates to more than 40,000 teachers (NBPTS, 2005). The certification process is rigorous and only one-half of candidates are successful.

To accomplish the NBC process, teachers have to complete extensive portfolios, over a 4–6 month span, that profile their work with students, school, and community. The portfolio entries include descriptions of the teaching and learning in the teacher's classroom, videotapes of and commentaries on the teacher's interactions with students, and examples of and commentaries on student work (Porter et al., 1996). The assessment center exercises focus on subject matter content knowledge and require teachers to devise instructional plans, analyze examples of student work, view and respond to videotapes, and participate in simulations (Porter et al., 1996). In brief, this certification process is designed to engage teachers in teaching for individual student attainment (Pershey, 2001).

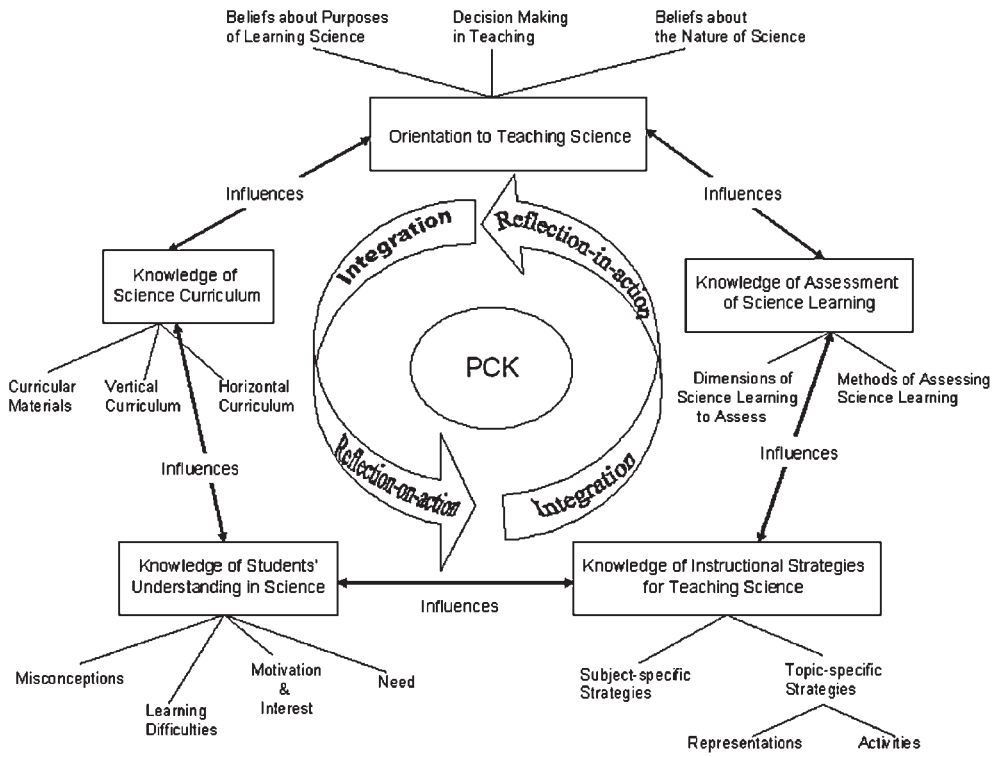

Figure 1. Pentagon model of pedagogical content knowledge for science teaching.

Portfolio Creation Processes and Teachers' Knowledge Development. Teachers seeking the NBC are required to put together a portfolio in accordance with the specifications, specific to both student age level and subject matter field, given in the directions and materials developed by the National Board. The portfolio offers teachers the opportunity to sample and present their actual classroom practice over a specified time period (NBPTS, 2004). The portfolio consists of several entries, which were developed in collaboration with practicing teachers who verified their feasibility in school settings and their value as both assessment entries and vehicles for professional discussion and growth (NBPTS, 2004).

In general, teachers prepare their portfolios for the National Board assessments by videotaping their teaching, gathering student work samples and other teaching artifacts, and providing detailed analyses of their practice. The videotapes of teaching practices and samples of student work are to be supported by teachers' commentaries on the goals and purposes of instruction, reflections on what occurred, the effectiveness of practice, and the rationale for their professional judgment (NBPTS, 2004). Basically, the portfolio is designed to capture teaching in real-time and in real-life settings, thus allowing trained assessors to examine how teachers translate knowledge and theory into practice (NBPTS, 2004). This translation is, likewise, a core concept of PCK.

The research reported here evolved from the belief that the NBC process, particularly the portfolio creation, provides candidate teachers with opportunities to develop their knowledge for teaching. This belief was grounded in our analysis of Adolescence and Young Adulthood (AYA: i.e., students aged 14–18 years) science portfolio entries. For each entry of the AYA Science portfolio, we analyzed standards, requirements, specific directives to complete each requirement, and knowledge bases necessary to complete each entry (see Appendix A). As a result, we concluded that the portfolio creation process requires teachers to integrate different knowledge bases, and that integration might ultimately facilitate PCK development. In this regard, it

is our goal to make a positive stride toward new understandings of the relationship between the NBC process and PCK development.

Methods

Research Design

This research was conducted as a multiple case study. This method is used to inquire into a particular phenomenon using a number of cases (Stake, 2000). Since we were interested in the effects of the NBC process on PCK across candidate teachers, we examined various cases from among a group of teachers. However, analyzing and interpreting individual teachers' cases was concentrated on understanding the inquiry (i.e., how teachers develop PCK while going through the NBC process).

This approach also evolved from the awareness that detailed case studies of teaching have frequently resulted in well-documented and insightful accounts of teachers' thoughts and practices (Calderhead, 1996). In this regard, Carter (1990) suggested that case methodology be used to tap the sources of teacher knowledge and ways of thinking about learning to teach. We also believe that this approach will aid our effort to avoid falling under the admonition given by Loughran, Berry, and Mulhall (2006) that ''much time and energy has been expended evaluating PCK as opposed to exploring concrete examples of how teachers teach particular content topics in particular ways that promote understanding'' (p. 14).

Due to the complexity of PCK (Baxter & Lederman, 1999), we employed a multiple method approach by using a variety of data sources and data analysis methods. The use of multiple method approaches ''appears superior, not simply because they allow triangulation of data but because they are more likely to capture the complex, multifaceted aspects of teaching and learning'' (Kagan, 1990, p. 459).

Participants

The participants for this study were three experienced high school science teachers who were participating in the NBC process. Table 1 presents background information of the participants. For confidentiality, all were given pseudonyms.

At the time of this study, the teachers were going through the NBC process together and taught at the same high school in suburban Atlanta. Each of the three teachers is female and White. All of the three teachers taught chemistry.

Data Collection

Data were collected from multiple sources including classroom observations, semistructured interviews, lesson plans, teachers' written reflections, students' work samples, and researcher's field notes. We observed three subject matter units for each teacher using a nonparticipant observation method: one unit at the beginning, one at the midpoint, and one at the end of the entire portfolio creation process. For each unit, at least three class periods were observed.

Given that we cannot observe everything we might want to know, we also conducted interviews in combination with the observations of each unit. The interviews allowed us access to the context of teachers' action (Seidman, 1998) and to understand the meaning of that action from the teachers' points of view (Kvale, 1996; Shore, 1986). In this study, four different kinds of interviews were carried out. The first-round interviews delved into the teachers' backgrounds and their orientations to science teaching. In that PCK appears in the planning, interactive, and postactive phase of teaching (Hashweh, 2005), the second and third interviews were conducted before and after each observation, respectively. The second-round interviews concerned planning for a specific class they were teaching. After observing the class, we interviewed the

Table 1
Background information of participants

	Amy	Lucy	Jane
Education	B.S/M.Ed	B.S/B.Ed/M.Ed	B.Ed/M.Ed/Specialist
Science background	Physics & Chemistry	Physics & Chemistry	Biology & Chemistry
Teaching years	21 years	11 years	8 years
NBC	Candidate	Candidate	Candidate

teachers about teaching that lesson in general and particular classroom incidents noted during the lesson and seemed relevant to their PCK. This was the third-round interview. The fourth-round interviews were to allow the teachers to articulate the changes in their teaching practices that occurred through the NBC portfolio creation process from their own perspective. All observations and interviews were audiotaped and transcribed.

Lesson plans and students' work samples including assessments were also collected as data sources. Moreover, we asked the teachers to write reflections on their teaching, which in some cases served as precursors for reflections that might be included in their NBC portfolios. To describe the context of the classroom and affirm the reliability of the observation data (Silverman, 1993), we made short notes at the time of the observations and expanded notes as soon as possible after each observation. Also, we recorded problems and ideas that arose during each period of observation in a reflection journal.

Data Analysis

The data from the multiple sources were analyzed through two different analysis approaches: (a) constant comparative method, and (b) an enumerative approach. In the constant comparative method, the data analysis focused on the identification of regularities or patterns in interview and observation transcripts without using a preestablished system of categories or codes. Instead, we developed categories on the basis of the data through an interactive process during which the data were constantly compared (Charmaz, 2000; Glaser & Strauss, 1967). The two authors independently coded the transcripts, and any disagreements were discussed until a consensus was reached. Also, patterns and themes emerging from the data were discussed and refined using investigator triangulation (Janesick, 1994).

We also employed an enumerative analysis approach (LeCompte & Preissle, 1993) so as to reduce the subjectiveness of qualitative coding and to facilitate identification of the characteristics of each teacher's PCK. The enumerative analysis is used to quantify verbal data. To this end, we first created the "PCK Evidence Reporting Table (PCK ERT)" based on the pentagon model (see Appendix B). Using those categories and subcategories in the PCK ERT as a preestablished set of codes, the two authors coded together the same observation transcripts, again with a computer-assisted qualitative data analysis software, Atlas.ti (Muhr, 1997). At the same time, we tallied the occurrences of each sub component in the PCK ERT. In the case that clarification was needed for coding, we referred to pre- and post-observation interviews and written reflections associated with the observation being coded and then made notes in the margins of the PCK ERT. The results from the enumerative approach were compared with and integrated into the results from the constant comparative method in order to provide methodological triangulation (Denzin, 1978).

Findings

Data analysis indicated that the NBC portfolio creation process affected five aspects of the candidate teachers' instructional practices: (a) reflection on teaching practices, (b) implementation of new and/or innovative teaching strategies, (c) inquiry-oriented instruction, (d) assessments of students' learning, and (e) understanding of students as individuals. In the following section, we argue how these aspects were reflected in PCK development. Some of the findings will be presented as teachers' classroom stories that portrayed best what emerged from the data. The stories were verified through triangulation of multiple data sources such as observation, interviews, written reflections, and field notes and then restructured for smooth flow.

Reflection on Teaching Practices

Another study on PCK (Park & Oliver, 2007) conducted simultaneously with the same participants as this present study revealed that reflection plays an important role in the development and integration of the components of PCK. For example, in Amy's metal lab, students were asked to test as many chemical and physical properties of a variety of metals as they could. Because Amy took safety issues into consideration in planning the lab, she gave the students a chunky form of metals, not metal strips. However, when students hit chunky zinc with hammers, it shattered rather than bent as was expected. During the lab, Amy noticed that

that event caused students to develop the misconception that zinc is not malleable. After the lab, she reflected on the event and hammered zinc by herself to figure out why that event happened. Finally, she found that the chunky piece ''appeared'' brittle because they had little pieces that jut out and easily broke off due to oxidation, and a little zinc piece was bent when it was hit and carefully observed. With this understanding, she came to design a follow-up lesson incorporating several instructional strategies to confront students' misconception about zinc that they developed during the lab (refer to Park & Oliver, 2007, for detailed description). She also reshaped her metal lab in a way to reconcile the conflict between safety and students' misconception for future use. This example supports that reflection enables teachers to develop components of PCK (i.e., knowledge of subject matter, student understanding, and instructional strategies) and to integrate them in an effective way.

Consistent with this finding, Loughran and his colleagues (2000) identified reflection as an element of PCK and concluded that PCK is developed over time through reflection. In a study that examined preservice teachers' PCK development that occurred in the context of a course module about the use of particle models, De Jong, Van Driel, and Verloop (2005) found that stimulated reflection on the teachers' practical experiences developed their PCK.

One of the five core propositions of the National Board Standards is that ''Teachers think systematically about their practice and learn from experience'' (NBPTS, 2004). This proposition emphasizes the importance of a teacher's reflection in becoming an accomplished teacher. In keeping with this proposition, candidate teachers for NBC are asked to write reflections for each of the four entries of their portfolios. Hence, it is not surprising that as the teachers were going through the process, they became more reflective. As corollaries to the increased amount of reflection, the participant teachers reported more positive attitude toward reflection, greater recognition of the goals of their instruction, and deeper insight into their actions of specific students and groups of students.

There was evidence, however, that the process influenced not only the amount of reflection, but also the content of reflection. For instance, the teachers stated that they reflected more on students' achievement throughout the process of putting together the portfolio. This was because the guidelines for creating the portfolio were interpreted by the teachers to put an emphasis on the National Board standards related to student achievement. Amy's statement below gives a representative example of this feature. She was speaking in reference to how she felt after having put together the portfolio:

> I think of students as individuals, more focusing on their achievement in science, like what kinds of difficulties a student has in learning this unit, why this student dislikes science, how this student's science fair project is going, how I can help them to succeed in science learning. (Amy, Interview 3)

Besides the focus on students' achievement, the teachers grew to reflect more on ''why'' questions. Throughout the portfolio creation process, ''much of their reflection on their teaching shifted toward why it works from what works'' (Field note, 1/18/2005). As the teachers sought answers for ''why'' questions, they became more analytical about their instruction, acquiring the habit of questioning themselves about their instructional decisions. In addition, through the process, the teachers came to be more goal oriented and to engage in purposeful planning. [One teacher from the larger study that examined teachers' experiences with NBC process called it ''becoming more intentional about teaching'' (Oliver & Peker, 2004).] These changes are nicely exemplified in the excerpt below:

> I think what National Board has done has made me more purposeful, made me focus on what are my goals for this lesson? Not just, ''Hey, let's have an awesome day of science!'' You know, ''What are the specific goals that they need to walk away with today?'' which is good. (Lucy, Interview 3)

Taken together, the NBC process provided the candidate teachers with a task that they accomplished by creating more frequent opportunities to be reflective and analytical with regard to their practices. This produced a concomitant refocusing on students' achievement and the explication of reasons for their actions.

But beyond the National Board standards emphasis on reflection and the requirement of refection sections in portfolios, there were other aspects of the process that appeared to drive the teachers to become

better reflective practitioners. On the top of this list was the analysis of videotape from their classroom instruction sessions. When they observed themselves teaching on the videotape, the teachers started recognizing aspects of their teaching that had previously escaped notice. As an illustration, Amy videotaped her honors class for the portfolio entry 2, ''Active Scientific Inquiry,'' and her College Preparatory (CP) class for portfolio entry 3, ''Whole Class Discussions about Science.'' When she watched the videotape of her CP class, detached from her own presence on the tape to whatever degree she could accomplish, she felt that the discussion was not going well. But then she took a closer look. What she saw going on in the classroom was a teacher who had quite different expectations between CP and honors students with regard to their classroom behaviors. She explained in a subsequent interview:

> It [watching the CP class on the videotape] made me realize that the difference between my honors and my CP is I don't expect my CP students to discuss as well as I do my honors. In my honors class, students can interact. . . But in my CP class, I'm worried someone will get up to punch someone else out, you know. . . being smart is not necessarily a good thing. (Amy, Post observation interview 4)

She further came to understand that she had not provided adequate opportunities for CP students to learn *how* to discuss. In attributing a reason for this, she concluded that she simply did not expect that the CP students could be good participants in a discussion. After recognizing this, Amy decided to work on making the CP students better at discussion rather than to revert to her honors class for the whole group discussion entry. She spoke of her decision this way:

> My first instinct was, ''Well, I'm going to go back to honors. I know I can get them to do a good discussion.'' But my next thing was, ''No, I'm going to make my CP become better discussers,'' which I haven't tried before. I'm going to consciously try to have them do little activities where they learn to interact without getting feelings hurt and learn how to discuss things. (Amy, Post observation interview 4)

She ended up videotaping a discussion section in her CP class for the portfolio entry 3 just as the deadline for portfolio submission was approaching. The lesson videotaped involved activities and discussion to identify unknown substances (Amy, Observation 10). She reflected on that entry and found that CP students developed their discussion skills.

> Discussion about the identity of the six substances is an excellent way to help students develop their problem solving skills by letting their peers challenge their assertions. . . I was able to monitor each student's participation and progress in listening, respecting, and responding to every student's ideas. (Amy, Written reflection)

Amy's story represents the power of reflection as a component of one's analysis of teaching and as a means to change. Had Amy not gone through the NBC process, she might never have realized how low expectations for the CP students' discussion capabilities limited her effectiveness, and her CP students would have faced an additional incidence of restricted educational opportunities. In order to enhance the students' discussion skills, she had to carefully redesign lessons and develop appropriate instructional strategies for those students. By our working definition, her PCK expanded as a result. This feature confirmed that reflection provided a dynamic quality to the mechanism of PCK development.

Implementation of New and/or Innovative Teaching Strategies

It might be assumed that NBC candidate teachers use the lessons or activities with which they are already familiar and accomplished for their portfolio entries. However, the three candidate teachers also employed new activities or instructional strategies that they had not previously implemented for some of those entries. By doing this, their repertoire of instructional strategies for teaching a particular topic was expanded and as a result their PCK developed. For instance, Amy and Lucy developed an ''element and compound unit'' for

their National Board portfolios based on the labs they had learned at a science teachers' conference. In the interview conducted after the conclusion of the unit, Amy answered the question of ''whether she had done this lab before'' in the following way:

> No. I've done a lot of inquiry labs before. But I haven't done this one. This one is one I learned at a chemistry education conference a couple of years ago. I thought ''it is great!''. . . I wanted to do it last year, but we've never been able to figure out how to get it in. National Board sped up doing it. It might not have happened this year. (Amy, Post observation interview 2)

This passage suggests that the process itself catalyzed the implementation of innovative activities, labs, or instructional strategies. Once teachers get involved in the NBC process, they attempt to meet the National Board standards for teaching performance throughout every aspect of their classroom practices. They try to figure out the best way to demonstrate that they are accomplished teachers based on what they have previously done. If they realize that there is a gap between what they have done and the standards, then they search for something that seems to better address the standards than what they have previously done. This point is nicely described by Lucy below:

> National Boards actually allows you to look at yourself and analyze your strengths and weaknesses, and actually change something, actually have the opportunity to say, ''Well now I've thought about doing this for years. I'm really going to go through and do this because I think this will be effective, or no I've been doing this for years and I thought all along it was accomplishing the goals.'' (Lucy, Interview 3)

Lucy and Jane provided representative examples of how the portfolio creation process motivated them to develop and employ new instructional strategies. Lucy started having students write journals to scaffold their learning (Lucy, Observation 2). She thought that this tactic might be included in her entry 4, ''Documented Accomplishment: Contributions to Student Learning.'' In describing this approach she said,

> This year, to help students achieve and master material, I've been having some kids, who just are so lost, keep a journal. . . I was a little more motivated because of National Boards, because I thought, ''Oh, maybe I can document that.'' (Lucy, Post observation interview 4)

In her written reflection, she recorded how the journaling helped one student having obsessive compulsive disorder:

> ''I keep in weekly contact with Sharon's mother. I require Sharon to journal about her homework time and get weekly teacher and parent signatures. At first Sharon resented this, but now sees it as a tool to keep her on track.'' (Lucy, Written reflection)

To complete portfolio entry 3, candidate teachers have to submit a 20-minute unedited videotape of a whole class discussion. Jane confessed that the 20-minute time limit forced her to come up with the strategies to effectively facilitate intensive and in-depth discussion:

> ''When you have to get something in 20 minutes, you have to think about time management a lot more. Time management has forced me to be more efficient and get to the point. I need to use different strategies to lead discussion in-depth.'' (Jane, Post observation interview 4)

These examples reveal that the NBC process triggered the expansion of their knowledge base of instructional strategies. Each teacher believed that this expansion had a subsequent benefit for their students. Given that knowledge of instructional strategies is one of the five components of PCK as described by the pentagon model, we again find that the NBC process was positively related to the teachers' PCK development.

Inquiry-Oriented Instruction

The National Board standards for the AYA Science certification stress inquiry-based learning. Creation of the portfolio includes the requirement of an inquiry-based teaching entry in which teachers are asked to include three discrete segments of science classroom inquiry documented with a videotape. The segments are supposed to show: teacher interactions with students at the beginning of the lesson; teacher interactions as the students collect data; and teacher engaging the students in analyzing, interpreting, and synthesizing the results. Accordingly, the NBC process has the potential to foster the teachers' exploration and analysis of their inquiry-oriented instruction. Much evidence emerged in this study to support this assertion. Consider Jane's account below:

> There's a big portfolio in science where you have to demonstrate an inquiry lab. So I am thinking twice about lab exercises that I do on a weekly basis. Instead of making it more of a cookbook lab, I've been trying to make it more of an inquiry process. (Jane, Interview 3)

Over time, evidence accumulated that the portfolio creation process was influencing the teachers to become more aware of the importance of inquiry in science teaching. For example, Lucy's typical Advanced Placement (AP) classes were not inquiry oriented, but the NBC process inspired her to transform her AP classes into more inquiry-oriented lessons. In a pre-observation interview, Lucy said,

> In AP, you do tend to teach toward a test. I mean you're teaching really to prepare them for the test and college. But a problem is that you do have to teach thinking. So I have to... kind of venture into inquiry with AP... NBC forced me to really think about it." (Lucy, Pre observation interview 5)

In the middle of that interview, "Lucy suddenly came up with an idea to convert lecture into an inquiry lab for AP. She described her idea with great animation for 10 minutes" (Field note, 11/19/2004):

> I haven't really been able to wrap my brain around how to make an inquiry [lab]... well, this next thing that I'm going to do is colligative properties... Oh! I'm real excited about this and it's good, because I'm running out of time and I've got to fit a lot of stuff in one, so I'm going to teach it through a lab. I'm going to tell them what sections to read in their book. And then I'm going to give them an unknown powder of ionic compounds... I'm going to let them identify it and give me like three proofs... I might try and think of something, some kind of murder mystery or some purpose for them to identify the chemical... I'm so excited because I don't know why I just didn't think about it that way... I think I'll talk in my NBC reflection, I'll talk about the other lab and how it allowed me to kind of venture into inquiry with AP. (Lucy, Pre observation interview 5)

Lucy ended up creating a unit about chemical compounds and decided to videotape the lab for her portfolio entry 2. Before the lab, she confirmed that her strong positive feelings had continued,

> I felt more empowered to do it. Would I have come up with this inquiry unit if it had not been for National Board? Maybe I wouldn't have been as motivated. I've been wanting to and I think National Board just gave me the kick in the butt to actually make me do it. (Lucy, Pre observation interview 7)

After teaching the unit, in her reflection, she wrote,

> True inquiry means there is more than one way to solve a problem. Having freedom in lab to design their own experiments and being able to articulate their thoughts was especially important for this group of students since they make connections and are very creative in their solutions. (Lucy, Written reflection)

Lucy's story allows us to grasp how the NBC process encourages candidate teachers to shift toward more inquiry-based labs. Inquiry-oriented instruction is one of the major subject-specific strategies for teaching

science, and as such is also one aspect of ''orientations to science teaching'' that was identified as a component of PCK. In this regard, the teachers' improved understanding of inquiry-oriented instruction stimulated by the NBC process contributed to the development of their PCK.

Assessments of Students' Learning

The National Board standards emphasize teachers' commitment to students' learning and their responsibility for managing and monitoring students' learning. Under this overarching standard, ''Assessing for Results'' is the label given to one of the standards that candidate teachers need to meet for portfolio entries 1, 2, and 3. Particularly, for entry 1, ''Teaching a Major Idea over Time,'' they are required to analyze students' work samples in terms of the changes in an individual student's understanding of the subject matter. In addition, they have to provide a rationale for the assessment they employ.

It became clear that the NBC process affected multiple aspects of the teachers' assessments. Two of these will be explored in depth. The first is an increased awareness of the importance of diagnostic assessment. The second was increased use of multiple means to assess the learners.

Diagnostic Assessments. The teachers came to be more aware of the importance of diagnostic assessments in tailoring instruction to meet individual students' needs. Jane pointed this out when she said,

> One of the biggest things I have learned from going through that [NBC] is that I was not using student progress in the class enough to address lessons that were going to be coming up. I was busy and a lot of times I didn't have a chance to really look at what my assessments told me. So I think I really learned to use that student assessment as a diagnostic more to tailor my lesson plans. (Jane, Interview 3)

As exemplified by this statement, the teachers came to a new appreciation of how assessments can play multiple roles within the teaching process; in particular, roles which served a formative function to improve students' learning rather than a strictly summative one. Although collectively realized, this perceptual change was individually implemented. Each of the three teachers' implementation had characteristics unique to them. Jane used reflective paragraphs to assess students' difficulties and misconceptions and to further adjust her instruction to their understanding levels:

> I stopped class several times this year and had students write reflective paragraphs to assess where they had misunderstandings . . . what trouble they have. Then I use this information to tailor my lesson to correct the misconception and provide more help to students who were struggling. (Jane, Post observation interview 8)

Similarly, Amy came to use more probing questions during class discussions and while monitoring small group interactions to gauge where her students are. Lucy, likewise, developed strategies to examine the learning of students who had not mastered the material. Her formative assessments were also used to point students toward extra help. Lucy illustrated the change in this way:

> By carefully examining students' assessment, I was able to distinguish between students who had mastered all the learning goals and those who had not. I held ''help sessions'' after school to reteach stoichiometry to those who needed more help. . . This strategy put lower achievers on par with their classmates. (Lucy, Post observation interview 10)

The teachers' shift in focus regarding the diagnostic role of assessments was closely related to their increased emphasis on, as discussed before, students' understanding. In brief, they began linking assessments with all stages and levels of student learning. Consequently, they employed several new strategies to improve the quantity and quality of feedback provided to students. For instance, Jane used rubrics, oral and written feedback, or graphic organizers to help students understand their progress in the course,

> Before, I could see myself giving an assignment to a student and then grading it. And now, just through the practices I chose to do for the portfolio, I now give them a rubric on how I will grade it and what I will be looking for as an evidence of their learning. Once you focus on students' learning, you feel like

> ''I have to do this.'' So I find myself using more rubrics and graphic organizers and teaching tools to help them learn or give them guides for the lesson. (Jane, Interview 3)

Whereas Jane's knowledge grew in response to using new tools and finding them to be essential, Amy's developing knowledge seems to grow from linking new assessment tools to fundamental understandings of the curriculum. Specifically, she identifies students' ability to solve certain chemistry problems as evidence of ''core understanding.'' She described it as follows:

> I communicated my criteria to students using lab goals, rubrics, pretests, oral and written feedback, and review sheets. Students used feedback to determine how close they were to achieving goals. In test reviews and post lab discussions, I emphasized solutions to problems that demonstrated core understanding of overall goals. (Amy, Written reflection)

Each of these teachers provided insight into the growth of their knowledge as a result of NBC, stimulating the use of student assessments for expanded purposes within their teaching. In each case they also point to the means by which this component of their PCK was linked to and influenced change in other components.

Using Multiple Assessment Methods within Classes. In addition to diagnostic assessments, the teachers came to employ more diverse types of assessments. As these teachers came to see more deeply into the role of assessments as a means to enhance students' learning, they attempted to employ their new arsenal of assessment tools in ways that would tell them exactly the level of an individual students' understanding. They also came to recognize the restricted value of a single instrument to accurately measure every student's learning. As a result, the teachers attempted to use a range of different assessments to obtain more accurate information about their students' learning. Lucy encapsulated this view saying,

> One of the biggest things I have changed is different assessment tools than just typical tests. I think, the traditional paper pencil tests, if that's all you're using, it does get frustrating, because you don't always see the results and they're very one dimensional. So if I know the kids who aren't going to do [the] test well, and you know somewhere they have some understanding of the content and those types of things over time get very frustrating. So I try to use a lot more diverse tools. (Lucy, Post observation interview 9)

Their use of various assessment methods was also connected with their improved awareness of the difference in learning styles exhibited by individual students. For the portfolio entries, they had to profile their students. This was typically operationalized in terms of demographic characteristics as well as available performance and personality indicators. To obtain a better understanding of the students' learning styles, the three teachers administered a ''multiple intelligence test.'' This led to a broader perception of the range of students' learning styles. To accommodate different learning styles, they attempted to differentiate both assessment methods and teaching styles. Amy reported,

> Most of my students have a kinesthetic learning style. So, I have been doing a lot more projects, and a lot of lab assessments. And, I've strived to design different kinds of assessments to accommodate many learning styles. I've done some portfolio kind of things and cartoons. In my CP classes, they had to build a model set. (Amy, Pre observation interview 4)

Over all, through the process the teachers refocused on the examination of student learning with an increased diversity of assessment methods and the addition of diagnostic assessments. Consistent with this, they clarified what evidence would document that students had achieved the goals of the lesson, and what methods were appropriate to accumulate that evidence.

This analysis also points toward a conclusion that while progressing through the process, the teachers developed their ''knowledge of assessment of science learning,'' which is a component of PCK. In the pentagon model, ''assessment of science learning'' encapsulates both ''dimensions of science learning to

assess'' and ''methods of assessing science learning.'' The former makes reference to factual, conceptual, process, etc., aspects of the structure of the knowledge that are to be acquired, whereas the latter points to the assessment tools. The development of both elements is clearly visible within this analysis, as is the relationship to the subsuming concept of ''assessment of science learning.'' The conclusion was reached that these teachers advanced their knowledge of assessment in ways consistent with knowledge held within the domain of expert teaching. Thus, the NBC process, by pushing teachers to consider assessment within a larger and more holistic view of teaching and learning, fostered the teachers' PCK development.

Understanding of Students

Our data analysis produced a variety of examples of how our participant teachers' knowledge related to ''understanding of students'' developed during the NBC process. To begin this section, one extended and compelling example will be used to illustrate the growth of participant teachers' knowledge of students. This story was recounted based on interviews, field notes, and written reflections, even though we did not put data sources for each quotation for the flow of the story.

David's story. During the school year when she was pursuing NBC, Lucy was teaching a 10th grade gifted chemistry course. One day, she administered a survey to the students in which she asked which of them worked after school, what subjects were their favorites, what languages were spoken in their homes, and so forth. She planned to use this information as one aspect of the aforementioned profiles she was required to assemble for her NBC portfolio entries. While Lucy was reviewing the student responses to the survey, one of her students, David, caught her attention. David had answered that his favorite subjects were physics and mathematics, and that he wanted to be either a computer software designer or a physicist. Lucy was surprised. David was ''not the sharpest tack in the box''; he did not seem to pay attention in her class. Thus, when she read his answer, she thought, ''Well, there's a big discrepancy with how he is performing.'' Lucy began to pay more attention to David.

A few days later, Lucy videotaped the chemistry class in which David was a student for her NBC portfolio entry. While reviewing the class videotape, she noticed that David doodled a lot during the class. She thought, ''Oh, great, how am I am going to explain that he is off task?'' She rewound the videotape and took a closer look at the scenes in which David was doodling. Two scenes struck her. The first occurrence happened as he was talking about how to convert measures of area to measures of volume. The second occurrence was when he talked about how he had interpreted the shape of the statue (an illustration used within a lab on metals) to be that of an arch not a triangle. ''Well, that's a math and a physics question. And that's when that kid was doodling. That's so cool.'' Lucy thought, ''His learning style may be more visual, because he is writing [it] down.''

The next day, Lucy asked David about his learning style. Surprisingly, he said, ''No, I'm very verbal. I get distracted visually. If I'm trying to learn something, I can hear it but I need not to look. So, I occupy my eyes on doodling, because that's less distracting than seeing all the things going on in the room.'' By her own admission, Lucy would have never interpreted the events that way. From this beginning, they were each motivated to build rapport with the other. Later that week, David came to her and said,

> ''I just started my medicine for ADHD, it's really helping. I am happier.''
> ''I guess that would be really frustrating if you're trying to pay attention and all of the sudden you find your mind is somewhere else,'' Lucy replied.
> ''Yeah, it was kind of frustrating because it wasn't always that I didn't want to pay attention.''

After this conversation, Lucy made a note not only for NBC portfolios, but for herself, ''I want to call that parent.''

Lucy subsequently sought to know more about David, so she looked in his folder (commonly known as the permanent record). She found that he had been suspended when he was in the ninth grade. She visited an administrator and asked what had happened. David had been suspended because he brought alcohol to school and sold it there. ''I'd like for his parents to get a good report on him,'' Lucy thought. After multiple

introductory phone calls, she visited David's home, and talked with his mother about what services were available to him. Lucy also provided individualized support for him. As a result, he began to score better on assignments, finished his science project early for extra credit, and took more responsibility for his own educational accomplishments.

David's story depicts how the NBC process provided both a motive and a means for a candidate teacher to take a closer look at individual students; and further, this example depicts how a teacher's improved understanding of students resulted in a transformation of the teacher's practice and new resources to improve the students' learning. In an interview, Lucy reflected on David's story in this way:

> I hope that would have happened normally. I hope it's just not externally motivated by National Board. But I wouldn't have known that he got paneled [suspended]. I never would have gone and looked in his folder... I don't know that I would have ever sought out that information. I think that there are definitely some things that I've gotten from the process. (Lucy, Post observation interview 5)

Lucy cried when she recounted David's story (Field note, 11/19/2004).

Increased awareness of Individual Students' Differences in Understanding. As the teachers came to look at their students more closely, they became more alert to individual student differences with regard to prior knowledge, achievement levels, interests, learning styles, etc. Lucy made this point in the following way:

> There are several things I've learned so far... The same three people maybe can answer every question, and therefore you think everything you're teaching is the right way. But, not to overlook everyone in the classroom! To realize that everybody in the classroom once again is not going to get the same material the same way! In being able to adjust to within even one classroom, be aware that everyone is not on the same level, just adjust some things that you're doing to better help everyone learn something. (Lucy, Interview 3)

This passage stresses how Lucy came to see that teachers should tailor their instruction to be responsive to individual students' differences. This was not new learning for Lucy, but rather the process of NBC made explicit to her some aspects of both students' needs and of how her instructional practice could respond to those needs which previously had been more latent or instinctive in nature.

Furthermore, there was impact of the NBC process on how these teachers viewed the larger issues of how detailed knowledge of all students influence teaching. For portfolio entries 1, 2, and 3, the candidate teachers wrote about their different instructional contexts that happened across a school day. One aspect of this is the requirement to describe their students in detail. They also had to analyze their teaching in terms of specific students' learning. For instance, in entry 1, they were asked to profile in depth the change in two students' conceptual understanding over time. The NBPTS make the assumption that without a deep understanding of individual students' conceptions, ability levels, learning difficulties, interests, and learning styles, the analysis of instruction and students' work samples would necessarily be superficial. Thus, the portfolio requirements pressed them to pay more attention to individual students. This aspect is well demonstrated in Lucy's description below:

> The students I profiled, I definitely know their style a lot and at a much deeper level than I would have. And it really made me think, well, "Am I changing my other students?" because I really did get to know what they were doing and their style and little things. And it made me wish I had smaller classes and more time to really do that for every student. (Lucy, Interview 3)

Taken together, the NBC process influenced the teachers to develop a better understanding of students. This better understanding was particularly exhibited with regard to how the teachers understood the different approaches to science learning and the varied levels of understanding of their students. The impact of students on teaching practices is the final issue to which we now turn.

Impact of Better Understanding of Students on Teaching Practices. The teachers' increased understanding of students was translated into their practices in several ways. Three of these areas of impact will be specifically examined: increased variety in their instructional modes, more careful student grouping, and increased tailoring of their instruction to individual students.

First, our analysis revealed that the teachers more frequently varied the types of instruction so as to accommodate different students' learning styles and ability levels across the process. The following excerpt supports this assertion:

> I am trying to vary the mode at which I teach to accommodate different learning styles and abilities, not always doing lecture or lab, but trying to incorporate other strategies. I'm kind of trying to give them a different twist for visual learners, arrange it around, or spatially on the board. I started with the auditory learners. . . so anytime I have something that I think is going to be hard for them to do, I try and do it many different ways. (Jane, Interview 3)

Second, in grouping students, the teachers took into consideration students' learning styles, interests, personal background, and personality as well as achievement levels to maximize every student's learning. Lucy's report below reveals some of the depth of her understanding of each student:

> I grouped Sherry (diagnosed with Obsessive–Compulsive Disorder) with Collin and Ben who listen very well and are considerate of others' ideas. .. Jane, Sharon and Cindy are all shy and I did not want their purposeful thinking to be rushed by a stronger personality or intimidated by a boy. . . Sam and Mika are quick, and I did not want them to give ideas away to others who could learn through discovery or to be frustrated with the slower pace of their classmates. . . Charlie can talk confidently about things, but does not always think things through, while Scott thinks better when forced to, such as when working with Charlie. (Lucy, Written reflection)

We do not suggest that this level of detail in thinking about student groups was entirely the result of the NBC process. But the analysis does suggest that thinking about issues such as grouping is pushed into the more conscious aspects of teaching for these teachers.

Last, the increased understanding of individual students enabled the teachers to offer individually tailored instruction. The individualized instruction was especially helpful for the students who brought special needs to the classroom. Lucy reported how she modified her instruction for a student who was bipolar:

> Jamie is bipolar and brilliant. His mother and I talk weekly about his progress and his medication. He gets concepts very quickly and does not pay attention when I am providing second explanations or additional practice for other students. After talking with his mother about how I can help him, I have him work through upcoming labs as soon as I've presented a topic so that he immediately has to apply class information in a tangible way. (Lucy, Written reflection)

This description shows that Lucy developed an instructional strategy appropriate for Jamie's need through communication with his mother. Frequent communication with parents was another strategy employed by this teacher to gain a better understanding of the students. Along this line, the National Board standards accentuate active interaction with parents. Candidate teachers are asked to document how they make connections with parents and how the connections affect students' learning in their portfolios. Because of this requirement, the teachers attempted to communicate more with parents through multiple avenues such as emails, phone calls, notes, etc. Amy put it in this way:

> I've always sent out progress reports to parents. But this year I'm sending out notes on them like what are we studying in class, what could they help their child with studying. And I've gotten back some positive response on that. . . I'm really glad I did that and I wouldn't have done that if it hadn't been for National Board. (Amy, Post observation interview 6)

Amy's account indicates that NBC fostered interchange between a teacher and parents; this interchange encouraged the parents to more significantly engage in their child's learning.

In summary, the NBC process facilitate the teachers' better understanding of individual students' differences in prior knowledge, learning difficulties, abilities, learning styles, and interests. Moreover, they took those differences into consideration in tailoring their instruction. Knowledge of students' understanding is one of the significant factors that promote PCK development. In this respect, the NBC process was highly related to the teachers' PCK growth.

Discussion

The NBC process had significant impact on the PCK development of the participant teachers. One of the salient effects of the process was to make the teachers more reflective and analytical about their own practices. In particular, they came to pose more ''why'' questions with regard to their instruction and to articulate the reasons for their actions. As teachers reflected on their teaching to answer those ''why'' questions, they came to recognize self identified deficiencies and internalized the need for change. Consequently, they enriched and expanded their existing PCK and ultimately changed their practices. According to Shulman (1986), a professional is capable not only of practicing an understanding of his or her craft, but also of communicating the reasons for professional decisions and actions to others. In this sense, the process itself supported the teachers to grow as professionals with the opportunities to articulate their professional experiences into the forms that are explicit, sharable, and communicable across the profession (Hiebert, Gallimore, & Stigler, 2002).

Another positive influence of the process was that teachers came to implement more new instructional strategies while creating portfolios. In that substantial changes in instructional practices often involve choosing to relinquish safe and familiar practices for the new and uncertain (Gess-Newsome, 2001), the process triggered instructional changes. While pursuing NBC, teachers became more willing to put activities or instructional strategies that would meet the National Board standards in their portfolios. This desire motivated them to put into practice previously untried instructional strategies that they believed would be effective. In short, the process served as a stimulus for the teachers to try out new activities and strategies, as implied in Lucy's metaphor of ''give me the kick in the butt.'' Moreover, because the highly structured National Board portfolios have asked some teachers to sometimes engage in practices that were very different than their ordinary approaches, it stimulated the use of new instructional approaches. As one component of the model shown in Figure 1, we believe that the use of new instructional approaches fed into processes by which there was enhancement of the teacher's PCK.

The teachers' learning from the NBC process occurred, perhaps most significantly, in inquiry-oriented science teaching and assessment. Within the model of PCK presented earlier, inquiry-oriented science teaching is one aspect of science teaching orientations, while assessments fall within the component labeled understanding of the assessment of student learning. The teachers demonstrated how their knowledge was increasing in both aspects as they went through the NBC process. This result coincides with the findings of the study that examined what candidate teachers for AYA science certificate learn from the National Board assessment process (Lustick & Sykes, 2006). They used a quasi-experimental methodology to identify, quantify, and substantiate learning outcomes of 120 candidates for AYA Science certificate from the participation in the certification process. They found that the candidates showed greatest gains in ''Scientific Inquiry'' and ''Assessment'' and concluded that the NBC process is an effective standards-based professional learning opportunity. But further, this identified growth in teachers' knowledge related to inquiry-oriented science teaching and assessment provides validation of the linkage suggested within the model of PCK.

As illustrated in David's story, the portfolio creation process encouraged teachers to take a closer look at individual students' interests, abilities, learning styles, personalities, family circumstances, and peer relationships. Consequently, they gained a better knowledge of their students, and this knowledge then became a basis for their PCK development. Based on their understanding of individual students, they differentiated their instruction modes, carefully grouped students, and offered individually tailored instruction.

On the whole, while going through the NBC process, teachers became more insightful about their instructional practice; took more time for reflection and self-evaluation; more closely monitored their instruction to make sure that worthwhile content was being taught to all students; more effectively adapted pedagogical procedures to meet the specific needs and abilities of their students at particular moments in time; and more fully accepted responsibility for guiding student learning. By the National Board standards, by

other ideals published in the literature of education, and by the teachers' own informal admissions, all of these adaptations moved this group of teachers forward toward being more effective in the classroom. Simply put, these teachers increasingly enacted instruction with the characteristics effective teachers are supposed to demonstrate. At the heart of their enactment and their new attainment was their further developed PCK.

Earlier, we considered the issue of whether teachers who successfully completed NBC must have initiated their pursuit already possessing sophisticated PCK, and thus their task was to demonstrate this knowledge in the creation of the portfolio. If NBCTs did not begin with sophisticated PCK then the alternative would suggest that the process of assembling the portfolio resulted in the elaboration and development of the PCK they previously possessed. Bond et al. (2000) did not address this issue when they concluded that NBCTs had more sophisticated PCK than other teachers. Our three participant teachers all came to the NBC process with many years of experiences and a significant level of knowledge in all five areas of the pentagon model of PCK (see Figure 1). Yet it is clear from this analysis that each of these teachers was confronted with the need for further elaboration of their knowledge within these components. In particular, they felt the need for more knowledge and understanding with regard to the teaching of science as inquiry and/or the assessment of student learning in science. This research demonstrates that the NBC portfolio creation process, through its requirements for structured reflection and classroom video analysis pushed the teachers to not only add to but also integrate the five components of this model in ways they had not done previously. Thus, although they certainly possessed PCK in the initial stages of the process, they ended with what can be called sophisticated PCK.

In this regard, it is clear that the NBC process acted as a catalyst for improving teaching. The teachers might become more reflective, more responsive to individual students' differences, more aware of diagnostic assessments, make more use of innovative strategies, and develop PCK through further teaching experiences without going through the NBC process. However, involvement in NBC accelerated the process of the teachers becoming better teachers. In this regard, the NBC process was highly related to teachers' knowledge development and improvement of practice. It is the NBC process that is an excellent professional development experience as well as recognition of accomplished teachers (NBPTS, 2001a, 2001b). National Board assessments are ecologically valid.

Implications

Parallel to our findings, research has asserted that creation of teaching portfolios encouraged pre- and in-service teachers to learn more about their teaching, to become more conscious of the theory and philosophy that guides their practice, to articulate their developing professional knowledge, and to develop a greater desire to engage in collaborative dialogues about teaching (Loughran & Corrigan, 1995; Park, Oliver, Johnson, Graham, & Oppong, 2007; Zeichner & Wray, 2001). This implies that creating teaching portfolios contributed to the growth of teachers, which will also contribute to a cumulative improvement of the teaching profession. In this regard, teaching portfolios can be used as a vehicle to stimulate teachers' reflection and analysis of practices in teacher education programs. In that videotaping of teaching inspired teachers to be reflective and analytic about their work, it is also suggested that videotaping of classroom practices be used for either assessment or development purposes in pre- and in-service teacher education.

This study showed that the NBC process had impacts on PCK and teaching practices. If the process was a procedure only to identify and reward teachers who are already accomplished, the beneficiaries of the process would be restricted to NBCTs themselves in that they may receive benefits such as financial incentives, reputation, or other probable benefits. However, it was evident that the NBC process itself is an excellent professional development experience, thus strengthening teaching practices of the teachers participating in it. Consequently, the beneficiaries of the process go beyond the teachers themselves to the students in their classrooms. Improvements, achieved through the professional development aspects of NBC, in teaching practices would certainly have positive impact on students' learning (Goldhaber & Anthony, 2004). Therefore, it is recommended that all agencies and stakeholders encourage teachers to get involved in NBC. As has been shown by research, both intrinsic and extrinsic motivating factors inspired teachers to engage in NBC (Oliver & Peker, 2004). Those motivators included financial incentives, colleagues' encouragement, improving teaching, meeting personal challenges, securing prestige/recognition, etc. Strategies to provide extrinsic motivators and to facilitate intrinsic motivation need to be adopted.

Finally, it appeared that the portfolio creation process positively affected teachers' teaching practices in powerful ways. To verify the sustainability of the effects of the process, however, longitudinal studies should follow. These longitudinal studies need to examine whether new instructional practices implemented or habits of reflection developed through the certification process are maintained after the portfolio construction experience.

The contents of this article do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government.

Appendix A

Entries of the AYA Science Portfolio and Required Knowledge Bases

Entry	Standards	Requirements	Specifications	Required Knowledge Bases
1. Teaching a major idea over time	- Understanding students - Understanding science - Understanding science teaching - Making connections in science - Assessing for results - Reflecting on teaching and learning	Three samples of student work from each of two students Written commentary Culminating assessment	Three instructional activities (one must show connections to technology) Related instructional materials Two students responses for each (include written feedback) Instructional context Planning instruction Analysis of instruction and student work Reflection Rationale for assessment	- Subject matter knowledge - Pedagogical knowledge - Knowledge of context - PCK (orientation to science teaching) - PCK (knowledge of student understanding) - PCK (knowledge of curriculum) - PCK (knowledge of assessment) - PCK (knowledge of instructional strategies and representations)
2. Active scientific inquiry	- Understanding students - Understanding science - Understanding science teaching - Engaging in science learner - Sustaining the learning environment - Promoting diversity, equity, and fairness - Fostering science inquiry - Assessing for results - Reflecting on teaching and learning	One videotape (20 minutes max) Written commentary	Three discrete segments of science inquiry: interacting with students to begin; interacting as they collect data; engaging them in analyzing, interpreting, and synthesizing. Instructional context Planning Videotape analysis Reflection	- PCK (orientation to science teaching) - PCK (knowledge of instructional strategies and representations) - PCK (knowledge of student understanding) - PCK (knowledge of curriculum) - Subject matter knowledge - Pedagogical knowledge - Knowledge of context

Entry	Standards	Requirements	Specifications	Required Knowledge Bases
3. Whole class discussions about science	- Understanding students - Understanding science Engaging in science learner - Sustaining the learning environment - Promoting diversity, equity, and fairness - Assessing for results - Reflecting on teaching and learning	One videotape (20 minutes max, unedited) Written commentary	A continuous, unedited videotape segment: interacting and discussing with students; showing scientific discourse among students; developing students' reasoning & thinking skills about important scientific ideas Instructional context Planning Videotape analysis Reflection	- Subject matter knowledge - Pedagogical knowledge - Knowledge of context - PCK (orientation to science teaching) - PCK (knowledge of student understanding) - PCK (knowledge of instructional strategies and representations) - PCK (knowledge of curriculum) - PCK (knowledge of assessment)
4. Documented accomplishment: contributions to student learning	- Reflecting on teaching and learning - Developing collegiality and leadership - Connecting families and the community	Description and analysis (10 pages max) Documentation (16 pages max) A reflective summary (two pages max)	Activities or accomplishments significant in the teaching context and what impact they had on student leaning (eight accomplishments max) Supporting the accomplishments; why are they significant? Patterns in accomplishments (within the last 5 years) What is most effective regard to student learning	- Knowledge of context

Appendix B

Evidence reporting table

Date: Class/ Period: Teacher:

Orientations to Teaching Science		K of Instructional Strategies and Representation						K of Students	# of Evidence of K of students	K of Curriculum	# of Evidence of K of Curriculum	K of Assessment		# of Assess
		Types of Activities	# of Activities	Types of Language Devices		# of Language Devices	Types of Content Elaboration	# of Content Elaboration							
Process	□	Inquiry-based lab		Explanation	Metaphors		Depth beyond the intended goal of text (Topic Knowledge)		Miscon-ceptions		K of vertical curriculum		Types of assess.	Diagnostic	
					Analogies										
Academic rigor	□				Similes									Formative	
		Hands-on		Examples	Related				Learning difficulty						
					Similar situation										
Conceptual change	□	Demonst-ration			Dissimilar situation									Summative	
				Narratives	Stories/ Anecdotes				Motivation/ Interest		K of horizontal curriculum		K of assessment methods		
Didactic	□	Simulation			Biography		Breadth beyond the intended goal of text (Domain Knowledge)								
				Illustration											
Activity-driven	□			Mnemonic devices					Need						
		Problem solving		Questioning	Recall/factual Qs										
Discovery	□				Attention-focusing Qs										
					Problem posing Qs										
Project-based science	□	Investiga-tion			Action Qs		Flexibility beyond the viewpoint of text		Diversity		Curricular saliency		K of students learning goals important to assess in a given unit		
					Reasoning Qs										
Inquiry	□				Comparison Qs										
		Etc.		Argument	Logic				Background						
Guided inquiry	□				Induction										
					Deduction										

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