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What Do Teachers Learn from a Problem-Based Learning Approach to Professional Development in Science Education?

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Abstract

In this study we evaluate the effectiveness of a problem-based learning (PBL) approach to professional development (PD), using concept maps as the main method. We chose to use concept maps as the main assessment method, because each teacher was focused on improving a different science unit and concepts maps allowed us to measure individual differences in conceptual understanding and pedagogical content knowledge of science teachers. We analyzed this development in science teachers' understanding by comparing pre-test and post-test concept maps of both content knowledge and pedagogical content knowledge. We found that participants developed understanding of several components of pedagogical content knowledge. Concerning development of content knowledge, results were positive for one subject matter group, and not significant for others. We conclude that PBL approach to PD may be effective for developing specific components of PCK of science teachers, but its influence on content knowledge is still not clear. The advantages and limitations of using concept maps in this context are discussed.

What Do Teachers Learn from a Problem Based Learning Approach to Professional Development in Science Education?

Introduction

This study analyzes concept maps to evaluate the effectiveness of a Problem-Based Learning (PBL) model for science teacher professional development (PD). In-service teachers who took part in this study participated in a two-week science education professional development program. The teachers differ in the grades and subject matter they teach. During the workshop, the teachers engaged in PBL activities designed to develop their understanding of science content knowledge (week one) and pedagogical content knowledge (week two). Because PBL emphasizes contextual richness and the development of conceptual connections, we decided that evaluation instruments that do not emphasize context and connections (e.g., multiple-choice questions) would be inappropriate for measuring change in teachers' science content and pedagogical content knowledge (Hmelo-Silver, 2004). We hypothesized that concept mapping, which allows participants to include context and encourages the inclusion of connections among concepts, could be an appropriate assessment tool for this PBL professional development study (Ruiz-Primo, Shavelson, Li, & Schultz, 2001).

Theoretical Framework

PBL as a Tool for Developing Professional Knowledge

Problem-Based Learning (PBL) was originally designed for medical education, and much of the research that supports it comes from studies of its effectiveness in medical schools (Albanese & Mitchell, 1993; (Barrows & Tamblyn, 1980); Dochy, Segers, Van den Bossche, & Gijbels, 2003). Albanese and Mitchell (1993) defined PBL as "an instructional method characterized by the use of patient problems as a context for students to learn problem-solving skills and acquire knowledge about the basic and clinical sciences" (p. 53). In medical schools, problems are presented as written case histories about patients (Barrows & Tamblyn, 1980). Students work through the problem by listing the facts of the case, hypotheses, and learning issues or questions, which they prioritize in terms of their importance to solving the problem. After that, students are released for a time to do self-directed learning around the issues they identified. They later reconvene to share what they have learned, agree on a diagnosis, and collaborate to make a decision regarding treatment.

While the majority of the literature on PBL has been conducted in medical schools, educators in other professional fields have begun to adapt PBL to their own contexts. PBL has been used in nursing (Newman, 2001 & 2004), undergraduate science courses (Allen, Duch, Groh, Watson, & White, 2003), preparation of preservice teachers (Butler, 2003; Derry, Seymour, Fassnancht, & Feltovich, 2001), undergraduate economics courses (Capon & Kunh, 2004), educational psychology (Chernobilsky, DaCosta, & Hmelo-Silver, 2004), and middle school science (Gordon, Rogers, Comfort, Gavula, & McGee, 2001).

In a recent meta-analysis of studies on PBL in medical schools, Dochy, Segers, Van den Bossche, & Gijbels (2003) found that, compared with students in traditional lecture-based courses, students in PBL courses gained slightly less knowledge but were better able to apply knowledge and higher order thinking skills. This study suggests that PBL has the potential to develop depth of understanding, rather than breadth. In another study, Capon and Kuhn (2004) compared learning outcomes on two concepts taught in an undergraduate economics course. Each of two groups of students learned one economics concept using PBL and the other using a traditional lecture and discussion method. They found that both groups of students could provide definitions for both concepts, but that each group could more fully explain the concept that they learned using PBL.

The process of problem-based learning is intended to mirror the clinical reasoning process required by professionals who have to make decisions without having complete information. One of the salient features of PBL is that PBL problems are ill defined and somewhat ambiguous. While there are many differences between physicians and teachers, the fact that they are both required to assess and make decisions with incomplete information means that PBL, which has been effectively used in medical schools, may also be an appropriate method to use in teaching instructional decision making to teachers.

The goals for learners participating in PBL include increased content knowledge, development of problem-solving skills, increased skill with professional decision-making, opportunities to collaborate with peers, enhancement of self-directed learning skills (Chernobilsky, DaCosta, & Hmelo-Silver, 2004; Hmelo-Silver, 2004; Kelson, 2004), and increased intrinsic motivation for learning (Hmelo-Silver, 2004). In any context, the question of how to accurately assess the intended learning outcomes of students in a PBL context has yet to be definitively answered. In the Dochy, Segers, Van den Bossche, & Gibels (2003) study, the authors suggest that the types of assessments used influenced the results; students who were asked to construct responses to open-ended questions showed higher gains. Hmelo-Silver (2004) has also demonstrated that traditional measures like multiple-choice tests may not be suitable to assess the type of deep, flexible knowledge that PBL fosters.

To date, there has been little work on using PBL as a tool for teacher professional development. One such study was conducted by Sage (2001), who presented a summer graduate course for teachers that was designed to help them develop PBL modules for their own classrooms. Students reported increased enthusiasm for teaching, a change in their teaching practices, and a difficult but stimulating learning experience. Teachers' pedagogical approaches developed through the course from focusing on technical teaching skills to taking a more constructivist view of the teacher's role, greater consideration of critical thinking, and increased use of authentic assessments. Like Sage, we were interested in measuring pedagogical content knowledge; however, we were also interested in assessing disciplinary content knowledge.

Pedagogical content knowledge (PCK) components and development

According to (Shulman, 1986), PCK is comprised of the synthesis of three knowledge bases: subject matter knowledge, pedagogical knowledge, and knowledge of context. Shulman (1986) wrote that PCK includes knowledge teachers should have about how to help students understand specific subject matter. It includes content and pedagogy that provide teachers with an understanding of how particular subject matter topics, problems, and issues are organized, represented, and adapted to the diverse interests and abilities of learners, and then presented for instruction.

Evaluation of PCK is complicated (Baxter & Lederman, 1999), since PCK is a highly complex construct that is not easily assessed. Conventional assessment methods are not suitable for integrating all aspects of PCK. For example, (Baxter & Lederman, 1999) claim that likert-type self-report scales, multiple-choice items and short answer formats include predetermined descriptions of desired teacher knowledge. These methods assume that a set of right answers do exist. These authors suggest that a combination of evaluation approaches is required, so that information can be gathered about what teachers know, what they believe, and the reasons for their actions.

Magnusson, Krajcik, & Borko, (1999) view pedagogical content knowledge and beliefs as the result of a transformation of knowledge from other domains, including subject matter knowledge and beliefs, pedagogical knowledge and beliefs and knowledge and beliefs about context. The relationships between these domains and PCK are reciprocal. These authors further define the concept of PCK as including 5 components: orientations toward science teaching, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understanding of specific science topics, knowledge and beliefs about assessment in science, and knowledge and beliefs about instructional strategies for teaching science. Here we adopt these categories, and modify them to the purpose of evaluating the PBL workshop. We operationalize each of the 5 categories using indicators related to the content discussed during the PBL PD workshop (see Appendix D for the detailed code list).

The component “orientations toward science teaching” has a central role in this model. Following Magnusson, Krajcik and Borko (1999) it includes teachers’ knowledge and beliefs about the purposes and goals for teaching a specific science topic at a particular grade level. These knowledge and beliefs guide instructional decisions about issues like daily objectives, content of students’ assignments, use of textbooks, and evaluation of students’ learning. Teachers’ orientations inform their understanding and practice of the other 4 components of PCK. Teachers can hold multiple orientations, including ones such as didactic and inquiry, that have incompatible goals for teaching science. For the purpose of this study we include orientations that were mentioned during the workshop as well as other orientations commonly presented in teachers’ maps (i.e., inquiry, conceptual change, constructivist, didactic and activity-driven).

The development of PCK requires drawing upon knowledge from each of the three domains of teacher knowledge (subject matter, pedagogy, and context). Thus, over time, a teacher’s “pyramid of knowledge” grows due to a combination of teaching, PD, and informal learning experiences (Veal & MaKinster, 1999). Different teachers’ PCK may develop in different ways (although they are participating in the same PD), because of differences in their knowledge in each component.

The Study Context: A PBL Program Designed to Develop Teachers’ Science and Pedagogical content knowledge

Effective teaching requires reflective practice – teachers must assess, diagnose, prescribe, and adjust their practice to reflect new research, knowledge, and experience. Recognizing the teacher as a reflective practitioner requires professional development

(PD) opportunities that change to meet teachers' needs over the span of their career. This project includes both preservice and inservice components. The preservice component takes place in undergraduate science education courses and post-baccalaureate courses that students take during their one-year internship, which is a requirement for teaching certification. This paper focuses on the inservice component of the project.

In this professional development effort, PBL was used as a tool to help inservice teachers from local K-12 schools examine problems of science content and pedagogy in a self-selected content area. During the first week, called the *Professional Working Conference* (*PWC*), forty-five teachers worked through *content dilemmas*, which were problems designed by facilitators to increase teachers' content knowledge in an area related to their self-selected content. During that week, they also were given time to develop units to teach in their classrooms the following year. During the second week, called the PBL *Focus on Practice* (*FOP*), twenty-two of the teachers who had participated in the *PWC* stayed to work through *teaching dilemmas*, which were problems of teaching practice developed by facilitators, presented in text or as video cases. The problems during the *FOP* focused on teaching issues, such as assessment, inquiry, and instructional decision-making. During that week, another activity teachers participated in was to determine and define problems that they would like to study in the upcoming school year using PBL with a small group of teachers. Teachers in the *Focus on Practice* group continue to meet in groups of teachers and facilitators throughout the 2005 – 2006 school year to study the problems of practice they identified and defined during the second week of the summer workshop using PBL. They do this with the support of other teachers, project facilitators, and researchers. Finally, participants will present their findings at a project-wide year-end poster session.

In this study we address the following questions:

1. How does participation in a Problem-Based Learning Professional Development program impact teacher-participants' science content knowledge?
2. How does participation in a Problem-Based Learning Professional Development program impact teacher-participants' understanding of pedagogical content knowledge?

3. What are the affordances and limitations of using concept maps for evaluating impact of PBL professional development on teachers' content knowledge and pedagogical content knowledge?

The third question relates to the main method we chose to use in this study. Before describing the study methods and results, we explain the background to our choice of using concept maps.

Tracking changes in knowledge with concept maps

As a part of our professional development workshop, concept maps, coupled with written paragraphs about the concept maps, were used as a tool for tracking changes in teachers' understanding of science content and pedagogical content knowledge. Concept maps were chosen as an assessment tool for several reasons. One was the difficulty with measuring the types of learning that PBL supports. Another difficulty relates to the fact that teachers were studying self-selected topics. While we recognized that there would likely be many difficulties associated with the use of concept maps as an assessment tool, the decision was made to investigate the possibility of their use for this purpose.

Concept maps are graphical representations of the connections students are making between concepts. They are meta-cognitive tools that can help both teachers and students to understand the content and process of their learning (Edmondson, 2000).

As assessment tools, concept maps may be used to document changes in knowledge and understanding over time. The use of concept maps as evidence of progressive change over time is one of the most promising applications of concept maps in assessing student learning. The structure of concept maps enables the evaluator to notice organizational patterns in the form of common errors or misconceptions, or in the form of essential critical nodes, around which expert knowledge appears to be organized.

Concept maps may also be useful for portraying learning that traditional methods of assessment have not captured effectively (like learning through the PBL method), and for assessing the types of knowledge that learners bring to bear on specific problems (Edmondson, 2000).

Establishing the validity and reliability of concept maps, however, has proven to be challenging. Ruiz-Primo and Shavelson (1996) and Ruiz-Primo, Shavelson, Li, and Schultz (2001) expressed concerns about the use of concept maps. It seems, however, that the reported methodological problems associated with concept maps have primarily arisen when seeking to compare concept maps that come from two different individuals rather than when comparing pre- and post- concept maps created by one person. For example, Jones, Rua, and Carter (1998) compared pre- and post- concept maps created by individuals working in pairs of novice and experienced teachers in order to examine the development of science teachers' content knowledge as a result of a science course. They compared the maps of the novice and expert teachers in each pair looking for common and different concepts. They found that teachers experienced growth in content knowledge, which was mediated through peers, tools and instructors.

Method

Participants

Twenty-two teachers participated in both weeks of PBL professional development workshops. Due to some absences, nineteen teachers completed both pre and post-maps for pedagogical content knowledge. Fifteen of the twenty-two teachers were female and seven were male. The average age of the teachers was 39 years.

Procedure and Instruments

During the first day of the first week, teachers completed a concept map of the "big science ideas" for their self-identified unit to work on (directions in Appendix A). On the last day of the first week, participants were handed back a copy of their map, and asked to add, delete, or make changes to their original map if they desired. A reflection worksheet asked teachers to write some paragraphs that identify and explain their changes. Our rationale for this task was founded on the primary use of the PBL process to present participants with problems that help them develop their own understanding of science and how students might come to understand the big ideas in science. Accordingly, if their content knowledge grew, and their understanding of how big ideas fit together changed, their concept maps between the first and last days of the week should reflect these changes.

During the first day of the second week, participants were given a short writing assignment in which they sketched out a vignette of an ideal science classroom, including ideas about "teachers' actions, students' actions, assessments, activities and strategies, and big ideas." Following this activity, they were asked to write down a few things that were important to keep in mind for the effective teaching of the unit they had previously identified.

Participants then drew a concept map that included these ideas in a representation of pedagogical content knowledge (see Appendix B for directions). These activities were repeated the last day of the week with blank sheets of paper. Participants were handed back their originals, this time after completing the second concept map, and were again asked to write some paragraphs to explain the changes they did and reflect about the process. Our rationale for this activity was rooted in the nature of the second week*,* which used the PBL process to pose instructional dilemmas about science teaching related pedagogical knowledge to participants (including topics of effective assessment, how to structure effective inquiry, and student understanding). As such, we expected that if participants had acquired new knowledge or understanding of these pedagogical content knowledge constructs (Shulman, 1986), these changes would be evident in their concept maps.

A third administration of the concept mapping procedure is planned for the end of the year, to track changes in teachers' content knowledge and pedagogical content knowledge as a result of one full year of participation in the project.

Scoring and Analyses

Since many difficulties in concept map analysis result from comparing concept maps that were created by different individuals, we restrict all of our analyses to changes that happen pre-post for the same teacher on the same task. A different difficulty centers on the validity of interpretations of scores from concept-mapping techniques (Ruiz Primo et al. 2001). Thus, we collected qualitative responses from the participants asking for their interpretations of changes in concept maps to corroborate concept map scores. Analysis of the concept maps was performed in several ways.

Content concept maps.

Because the teachers chose what content area they would represent in their maps, the map data that we collected addressed twelve different science topics. Teachers' choices to explore multiple science subjects presented several challenges for both developing and measuring content knowledge. First, design and facilitation of PBL content problems had to be flexible to meet diverse teachers' needs. Second, analysis of maps representing multiple topics for multiple grade levels made comparison of teachers' maps to an "ideal map" difficult. Instead, teachers' two maps were compared one to the other to identify comparative changes in knowledge and organization.

For each pre-post pair of concept maps, two researchers independently judged which map demonstrated better knowledge and organization of the science topic domain (the pre-, the post- or no difference), and the magnitude of the difference (no significant difference=0, small but noticeable difference=1, moderate difference=2, large difference=3). Researchers did not know which map was the pre-map and which was the post. When the two coders differed, a consensus coding was used (in all cases the two coders were able to agree on a coding). The interrater reliability of the two researchers' coding before agreeing on consensus scores was 0.9018. The criteria to judge better knowledge and organization are described in Appendix C.

The resulting codes were analyzed statistically and descriptively using the mean rating, t-tests (whether or not the average change was different from 0), and Cohen's d as an estimate of the overall effect size.

PCK Concept Maps

Nineteen participants created pre- and post- PCK maps. Each map was rated separately, according to the coding scheme in Appendix D. The coding scheme reflects a synthesis of Magnusson et al.'s (1999) conceptualization of PCK with the PCK topics addressed in the second week of the PBL professional development workshop. The four categories of PCK that were coded include curriculum knowledge, assessment, instructional strategies, and knowledge of students. With reference to topics addressed in the PBL workshop, the researchers developed multiple indicators for each category except for curricular knowledge. For example, under the category of assessment, we developed four indicators including (1) assesses students' scientific knowledge, (2) assesses students' scientific practices, (3) assessment informs instructional decisions, and (4) assessment is ongoing or embedded.

Magnusson et al. (1999) also propose that these constructs interact with teaching orientation, and consequently, with pedagogical content knowledge. Thus, teaching orientations were also coded. Full coding details may be found in Appendix D.

We used a four level scale for scoring each indicator or orientation (0 if the topic was not present, 1 if the topic was just mentioned, 2 if the topic was partly elaborated, and 3 if the topic was clear and explained). Each map was coded independently by two researchers. The researchers did not know which map was the pre-map and which was the post. Then the researchers discussed their ratings to reach consensus. For each category (except orientations) we calculated the category score using the average of the associated indicators. Pre- and post- maps were compared according to the average score for each category (except orientations). The Cronbach's Alpha interrater reliability of the two researchers' coding before agreeing on consensus scores ranged from 0.66 for the category of instructional strategies to 0.87 for the category of knowledge of students (Table 1).

<Insert Table 1 about here>

Analysis of individual participants' maps and paragraphs

Finally, analysis of one teacher's concept maps and paragraphs was used to explore in depth the changes that one teacher experienced and reported in her reflections on her concept maps. Cases help illuminate and characterize the broader group level changes. .Another reason for this analysis is to see how the additional information from participants' paragraphs influences the results and conclusions from concept maps alone. Analysis of all the paragraphs will be reported in future work, as well as individual case studies.

Results

Content Knowledge

How does participation in a problem-based learning professional development program impact teacher-participants' content knowledge? Twenty-two pairs of concept maps were analyzed by comparing knowledge and organization for the two maps. No significant change in knowledge and organization for the group as a whole was found [Mean change=0.32(1.36), p=0.568, Cohen's d=0.235] (Table 2). Initially, this is not a surprising finding because PBL research has demonstrated less impact on content knowledge, and greater impact on flexible types of knowledge such as problem-solving (e.g., Hmelo-Silver, 2004).

However, some unique qualities of the PBL professional development workshops that we held suggest that it is important to take a closer look at these data. For the content oriented PBL sessions, our participants were divided into three groups based on science discipline (Biology, Earth Science, and Physics). Participants in these three groups worked with different facilitators and engaged in different PBL content dilemmas. Comparisons by group shed further light on our findings and suggest a potential explanation. Results by group are shown in Table 2.

<Insert Table 2 about here>

The group results demonstrate that although there was no overall change in content knowledge for all participants, the three groups had very different experiences. Neither Earth Science participants nor Biology participants demonstrated a significant change in content knowledge; none of their post-maps were judged to be better than their pre-maps. The Earth Science results are closest to what we might have expected given previous research concerning the effect of PBL on content knowledge. This is because past PBL research has not demonstrated large impacts on participants' content knowledge.

Physics participants did demonstrate an increase in content knowledge. The increase in content knowledge for the Physics group is consistent for all the participants in this group. Some post-maps demonstrated a moderate change (e.g., new big ideas or better organization) and some only demonstrated a small change (e.g., addition of minor details). Several possible factors may explain the development of knowledge among the

Physics teachers. It is possible that the facilitation may have been better in this group. Alternatively, when we analyzed the participant application surveys, we found that the teachers in the Physics group were most likely to rate gaining content knowledge as an important personal goal for their professional development experience. Thus, their relative gain in content knowledge may reflect this group's particular interest in achieving this goal through the PBL PD program.

Results for the Biology group reflect some of the challenges associated with using concept maps to measure changes in teachers' knowledge during the PBL professional development workshops. In fact, the professional development planners had two purposes for using the concept maps with the teachers. The first reason concept maps were used was as a potential tool for measuring change in teachers' content knowledge.

The second purpose was to provide the teachers themselves with a conceptual tool for examining and reflecting on their understanding of a science content topic. In the case of the Biology group, the way they used the concept maps for the second purpose within their group suggests that it may be inappropriate for the researchers to simultaneously use the concept maps to measure change in these teachers' overall concept understanding. Although each of the Biology teachers had a separate map articulating their understanding of ecology at the beginning of the workshop, after the content workshop, four of the five teachers turned in virtually identical maps.

The teachers had used the concept maps as a tool to come to agreement on concepts that would be covered in a specific "Biomes Project" they were planning to implement in the coming year of their teaching. Because many of the teachers created highly developed maps of ecology at the beginning of the workshop, and they almost all turned in a highly specific and distilled map at the end of the workshop, the protocol that the researchers used to measure change in knowledge may not have been appropriate for measuring these teachers' maps. One option would have been to exclude the Biology teachers from the sample. However, the researchers decided to keep these teachers in the sample as evidence of some of the challenges that arise when conducting combined professional development and research in a flexible, teacher-centered PBL context.

Thus, overall, the findings for change in content knowledge for the teachers were mixed. These mixed results may reflect (1) the fact that PBL has not been demonstrated to be a powerful tool specifically for the development of content knowledge, (2) that there are challenges associated with measuring change in content knowledge in a flexible environment where teachers decide what they will choose to explore, and (3) that there are challenges associated with conducting a mixed purpose study that combines flexible, teacher-centered professional development with an attempt to evaluate results systematically.

One example of a Physics teacher's pre and post-maps is presented in Figure 1. This post-map was rated as moderately improved, since there were many appropriate details added in the post-map, and some added appropriate connections between nodes, but there were no additions of first-level nodes or "big ideas".

<Insert Figure 1 about here>

Pedagogical Content Knowledge

Our analyses of teachers' pedagogical content knowledge maps examined both pedagogical orientations and the four PCK categories of curriculum knowledge, assessment, instructional strategies, and student knowledge. There were no significant changes in teachers' pedagogical orientations between the pre and post-maps. The two orientations that were most often included and described in teachers' maps were constructivism and inquiry.

The orientation rating with the greatest overall pre to post-map change (a decrease, though not significant) was hands-on/activity driven orientation. Hands-on/activity driven orientation is defined as teachers valuing and including activities either without justification, or with justification that does not address higher order learning goals (e.g., because they are fun or engaging, rather than because they help students learn important science ideas or provide students with opportunities to model scientific practices). A significant decrease in this orientation could have been interpreted as indicating that the teachers were becoming more aware of learning-oriented reasoning and justification in their pedagogical thinking.

Results (Table 3) demonstrate change in two of the four PCK categories. Teachers' post-maps demonstrated better inclusion of curriculum knowledge ($t = 3.11$, $p = .006$). Their post-maps also demonstrated better inclusion of assessment ($t = 3.28$, $p = .004$). No significant change was found for categories of instructional strategies and knowledge of students. Both curriculum knowledge and assessment were pedagogical topics that were emphasized in the second week workshop with the teachers. Associated changes in teachers' maps indicate that the participants were, at the very least, developing an increased awareness of the importance of these components of pedagogy in their teaching practice.

<Insert Table 3 about here>

One aspect of knowledge of students (i.e., student misconceptions) was emphasized during the second week workshop. Although there was a modest and not significant increase in this one indicator of knowledge of students, overall, the second week workshop did not have an impact on teachers' understanding of this category of PCK. In future workshops, it might be worthwhile to spend more time emphasizing student misconceptions and the additional aspects of this category. Also, teachers may need more support in professional development for gaining understanding not just of what students' misconceptions are, but also specifically how to address them through instruction.

Interestingly though, instructional strategies were emphasized in the workshop. A more detailed look at the instructional strategies category suggests an initial explanation for absence of pre to post-map change. First, the overall pre-map average for instructional strategies is the highest compared to the other three categories, indicating that teachers were already moderately knowledgeable about this area of PCK. Only one of the individual indicators of instructional strategies (instructional decisions consider pros and cons) showed significant increase from pre to post. On the pre-maps, this indicator not only had the lowest score within the instructional strategies category, it also shared the lowest score for all indicators of all categories with two other rarely included indicators (knowledge of student misconceptions and knowledge of student trajectories of learning). Because so few teachers included "instructional decisions consider pros and cons" on their pre-maps, it is not surprising to find a small, yet significant increase in mention of this indicator on the post-maps. In contrast, because teachers were, in general, moderately familiar with the other indicators of instructional strategies at the beginning of the workshop, impacting significant change for instructional strategies overall was more difficult.

In summary, the second week workshop had a positive impact on two of the four components of pedagogical content knowledge. As a result of participating in the workshop, teachers were more likely to indicate that curriculum knowledge and assessment are important aspects of effective science education to consider and include in their teaching practice. We surmise that specific workshop emphasis on considering students' knowledge would be needed to impact this component. Furthermore, because teachers in general entered the workshop with some pre-existing knowledge about instructional strategies, more intensive and long-term professional development addressing this component of PCK could be needed to create meaningful impact for the in-service teachers in this area.

Analysis of individual participants' maps and paragraphs

In order to provide an illustration of specific changes that a participant in the workshop underwent, we analyzed the paragraphs and concept maps of one individual. Linda, an elementary school science teacher chose the topic of Earth, Moon and Sun. Linda's content knowledge pre/post concept maps demonstrated a small development of knowledge. The maps were similar except for the addition of two second-level nodes that include explanations for day and night ("spin on its axis"), and seasons ("revolves around the sun and tilt on the axis"). The paragraphs that Linda wrote to explain the big ideas in her unit show some misconceptions that persist in the post-map ("the moon has phases which directly relate to its spinning on its axis as well as its revolution around the earth"), some hybrid conceptions that did not appear in the pre-map ("due to the tilt of the earth's axis the sun is closer in proximity to us in the winter"), and some elaboration of ideas that shows development in understanding (e.g. explaining day and night). In general, the paragraphs add explanatory information, but do not change the score for these maps.

Linda's pre/post PCK maps (Figure 2) show a much larger positive difference than her content knowledge maps.

<Insert Figure 2 about here>

The post- concept map looks different than the pre-map, both in its organization and in the content that appears in the nodes. It includes more nodes and links that relate to new indicators (e.g. indicator IIIc - assessment informs instructional decisions). The map includes more levels and details, and presents some new central ideas (e.g. "Assessing my own teaching"), that did not appear in the pre-map. The post-map was rated higher than the pre-map for the components of curricular knowledge (pre-0, post-1), Assessment (pre-0.5, post-1.5), and Instructional Strategies (pre-0.83, post-1.17). The change in the component of curricular knowledge implies that Linda acknowledges the significance of content-knowledge, although her content maps showed a very small content development, and many big ideas were missing from her content knowledge paragraphs.

The paragraphs that follow Linda's PCK concept map add some information to the map itself. Participants were asked to describe an episode in a classroom of an effective and engaging science teacher teaching a topic in their unit. They were also asked to review their PCK maps after drawing the post-test map and explain what they changed and why. Linda mentioned the addition of "instructional teaching", and explained why she believes this is important: "I believe that this type of teaching must be a part of my teaching strategies because students seem to learn more with (this) type of teaching" (it seems that she meant instructional decisions instead of instructional teaching). About adding the part "assessing my own teaching" she explains the relation to the PBL process: "The PBL process defines a more effective way to pinpoint problems in my teaching and systematically work at improving my teaching strategies."

She also mentioned the advantages of inquiry - an issue not included in her map: "I found that even though the inquiry lesson does take longer, I feel that the students have a greater opportunity to learn". In the description of an effective science teacher Linda also includes some components that did not appear in her map. For example, in the pre-test paragraph she mentioned the use of questioning as an assessment tool, and the use of assessment to "adjust the lesson". These details clarify the level of knowledge of this teacher and her beliefs, and change the results in some of the PCK components compared to the analysis of maps only.

An important subject that appears in the paragraphs, but was not coded, is the teachers' view of the PBL process and what she learned from it. While reviewing her concept maps she writes: "Now I know of a more effective way to pinpoint weaknesses and eventually be able to overcome these dilemmas through the PBL process…I do believe I have a better picture of good science teaching, and I will be able to pinpoint problems quicker and be able to change my teaching strategies rather than muddle through knowing that something is wrong, but not having the tools to fix the problem."

This case study emphasizes the importance of using multiple sources in analyzing the knowledge of teachers. It also implies that one of the outcomes of PBL PD is teachers' understanding of the benefits of PBL for their own teaching. In order to follow the participants and check if and how they use what they have learned in this workshop we will use data collected during the year – from their lessons and their group meetings.

Discussion

The complexity of our finding regarding content knowledge is not surprising, and should be regarded within the larger PCK context. Possible explanations for this finding may be divided into three categories: 1. problems with methods, 2. problems with the workshop, 3. no problem, but an actual finding concerning the PBL method. More research is required to further examine these possibilities. Here we explain the problems, and several ways to investigate them:

1. Problems with methods:

- Participants were given their pre-test concept maps before creating the post-test maps, and many of them copied the same map with minimal additions.
- Some participants in the Biology group worked together.
- The current analysis does not include the paragraphs that participants wrote in addition to their maps. Including them may change the results.

2. Problems with the workshop:

- Differences among groups' content-knowledge maps may be related to the fact that facilitators in these groups managed their group work differently.
- In a separate paper we describe the criteria for a good content dilemma (Oslund, et al., 2006). Some of the problems used in the first week did not fulfill the main criteria.
- Learning content knowledge is a long-term process, and a week may not be enough time to make significant changes. Another session of tests is planned

to be given by the end of the year PD, and after analyzing the rest of the data this issue will be clearer.

3. A finding concerning PBL

- It is possible that concept maps are not the best assessment tool to evaluate content knowledge in a PBL context.
- Maybe it is easier to influence teachers' PCK than their content knowledge.
- If other possibilities are excluded, it may be possible to conclude that the PBL method is less effective for teaching content knowledge of in-service teachers. This conclusion is supported by literature from studies in medicine (Colliver, 2000).

In order to narrow the list of explanations we will have to wait for the final analysis of the PBL PD first year. For the following year we may consider using a different method to teach content knowledge in the workshop, and use the PBL for teaching other PCK domains. Alternatively, we may try to use a different assessment tool for evaluating content knowledge development in the context of PBL (for example, add a test of PBL application by providing an example of a situation where the PBL components are implied).

One other interesting result is teachers' view of the importance of content knowledge. Although their content-knowledge concept-maps did not improve significantly as a group, they did acknowledge the importance of content knowledge and added it to their post-test PCK maps. If we find development in teachers' content knowledge by the end of the year, it will emphasize this finding.

Conclusion and Implications

Evaluation of problem based learning professional development for teachers who are interested in different subject areas and teach different grades is a very complicated task. Considering the challenges reported previously concerning PBL evaluation (Hmelo-Silver, 2004) and the disagreement about the validity of concept maps for assessing teachers' knowledge (Baxter & Lederman, 1999), we expected the evaluation of content knowledge to be problematic. Our finding indicates that content knowledge of science teachers may be increased through PBL PD, but it might be affected by many parameters, including the subject matter, the quality of facilitation, the content problems used, the expectations of the participants and the amount of time devoted to PD. Considering all these complications, an implication of this study is to consider integrating different methods for enhancing content knowledge, or to use different approaches for different subject matters.

The situation seems to be clearer for development of PCK. PBL PD was effective for developing understanding in some components of PCK, mainly those that participants had less previous knowledge about (Assessment and Curricular knowledge). It should be noted that we do not assess all the aspects of PCK. In order to assess what these teachers do in their classes we will need to analyze data throughout the year and combine it with our finding concerning their knowledge and beliefs about PCK.

Concerning the use of concept maps, we conclude that this tool may be useful for evaluating a flexible program like the PBL PD, in terms of providing the same assessment tool for different subject matters and different grades. Concept maps can provide interesting insights of how different concepts or practices fit together for different participants. It was difficult to find a reliable coding scheme, but eventually we did reach an agreement and reliability in assessing the maps. Nevertheless, we recommended using a variety of assessment methods together with concept maps.

There seems to be an advantage to using concept maps for evaluating development of PCK components, since it is possible to get quantitative data out of qualitative analysis. This data may give information about individual participants' understanding in each component of PCK, the significance of each component for their teaching, and the rate at which they develop new knowledge in each component. This information could help in planning professional development in the future.

Appendix A

CONCEPT MAPS

Professional Working Conference

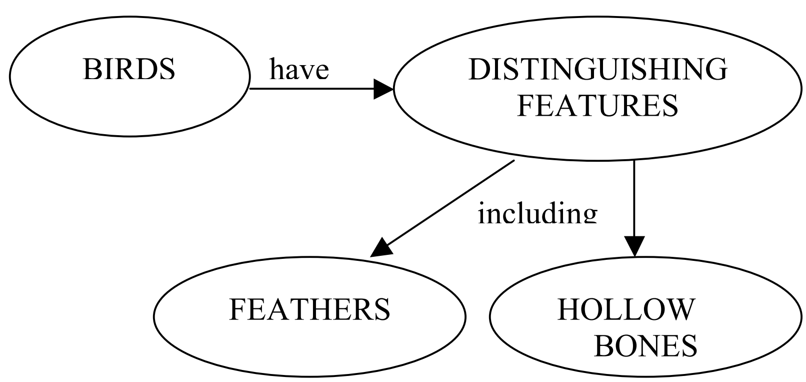
Directions: Design a concept map for your unit that displays your understanding of the science concepts. The following instructions are provided to guide your work.

1. **Identify the important terms or concepts that you want to include on your map.**
    - Please include:
        - science concepts you will be teaching
        - examples, experiences that you may use to illustrate the concepts

2. **Use circles, ovals, or other shapes to enclose each important term or concept.**
    - Each circle, oval or other shape should enclose only one term or concept. However, terms can be more than one word.
    - You may choose to use any arrangement of the shapes that you think is appropriate.

3. **Use lines with single-headed arrows to link terms that are related.**
    - Each line should link only two concepts.
    - However, there is no limit to the number of links stemming from or leading to any one term.

4. **Use a word or phrase of words as a label along each line to designate the relationship between each two connected terms. Each set of linked ovals and arrow labels should make a complete sentence.**



5. **Work and rework your map until you believe it gives an accurate picture of your understanding of:**

- the important ideas involved, and
- the relationships that exist among them.

Adapted from: Zimmaro, D. M., & Cawle, J. M. (1998). Concept map module [Online]. Schreyer Institute for Innovation in Learning, The Pennsylvania State University. Available: http://www.inov8.psu.edu/facculty/cmap.htm.

Appendix B

What is Effective Science Teaching?

If you were to peek into the classroom of an effective and engaging science teacher teaching a topic in your unit, what would you see? On a separate piece of paper, write a one-page vignette of an episode in this science teacher's classroom. Assume the conditions/situations are realistic. In your narrative of this scene, try to include:

- the teacher's actions and intentions
- students' actions
- assessment of the students' thinking
- activities and teaching strategies
- big ideas

Below list what you think are the necessary components of effective science teaching.

Organize the components above into a concept map. Put nouns and phrases in bubbles. Connect related bubbles with arrows. Label the arrows with a description of the relationship between the connected bubbles.

Appendix C

Criteria for Content Knowledge analysis of Concept Maps

1. Look at information in the **nodes** and compare them

a. Does one map's information in the nodes capture the domain of *big ideas* better than the other map's? (More important criterion)

b. Does one map's information in the nodes capture the *details* of the content area better than the other? (Less important criterion)

c. Higher order nodes are more important in making decisions than lower order nodes

2. In answering the above questions (focusing on information in nodes) consider:

a. Accuracy

b. Completeness

c. Coherence

3. Examine similar Chunks or clusters

a. Comparing similar chunks or clusters that happen in both A or B and examining organizational differences (using the criteria from (1) above

b. Looking for new chunks or clusters that happen in or A or B, and examining if those arrangements make for better (conceptual) organizations [*Note: this means that this could be potentially confounded with better knowledge, especially when nodes are re-organized around new nodes*]

4. Examine nodes that are in different locations in A and B, and judge which placements make more (conceptual) sense

5. Examine the linking structure differences in A & B

a. Look for links that make important conceptual connections between clunks (or nodes) indicating an understanding of the relationship between ideas, mechanisms, or systems.

b. Examine the types of links (e.g., conceptual, example of, etc.) as indicators of a better (conceptual) organization. Often this means that conceptual type links are preferred (but not always – examples are good too, when they are accompanied by concepts).

c. Bi-directional links may be better in many cases.

Appendix D

Categories and Indicators for PCK analysis:

I. Orientations toward the teaching of a particular subject

a. Constructivist framework

b. Conceptual change

c. Inquiry/ Discovery/ Project-based (student-centered)

d. Hands-on/Activity-driven (performing activities without conceptual coherence)

e. Didactic (Teacher-centered - Presenting facts, recall, memorizing, received scientific knowledge)

II. Curricular knowledge for a particular subject

a. Knowledge of learning goals, standards, or big ideas

III. Assessment for a particular subject

a. Assesses students' scientific knowledge (big ideas and understanding)

b. Assesses students' scientific practices (scientific literacy and skills)

c. Informs instructional decisions

d. Ongoing/embedded

IV. Instructional strategies for a particular subject

a. Activities build on each other (activity cycles)

b. Considers students' ideas and experiences

c. Include multiple appropriate representations and learning experiences

d. Instructional decisions consider pros and cons

e. Inquiry application

f. Motivating environment

V. Knowledge of students' understanding in a particular subject

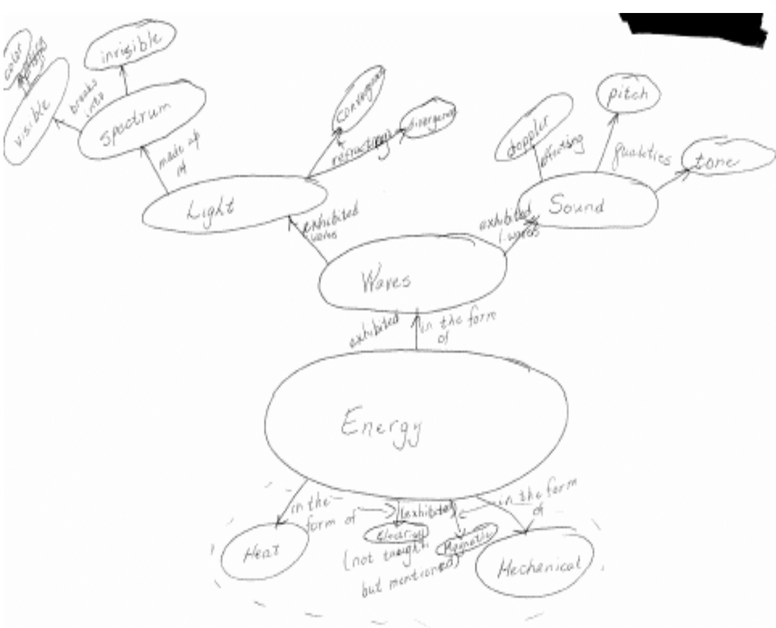
a. Knowledge of common student misconceptions

b. Connected to students' lives (authenticity)

c. Typical student trajectories of understanding (learning progressions)

Figure 1

Pre-concept map



Post-concept map

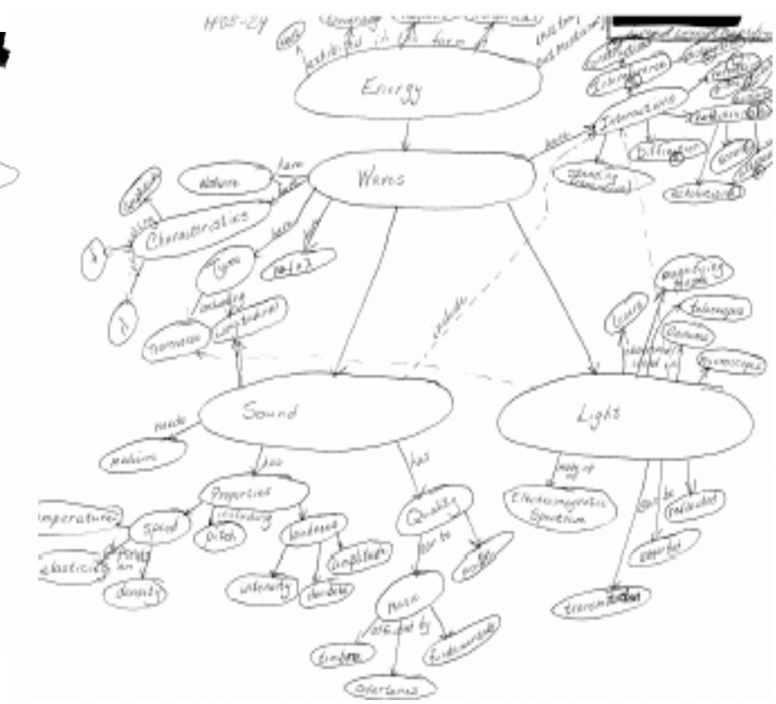


Figure2

Figure 2a

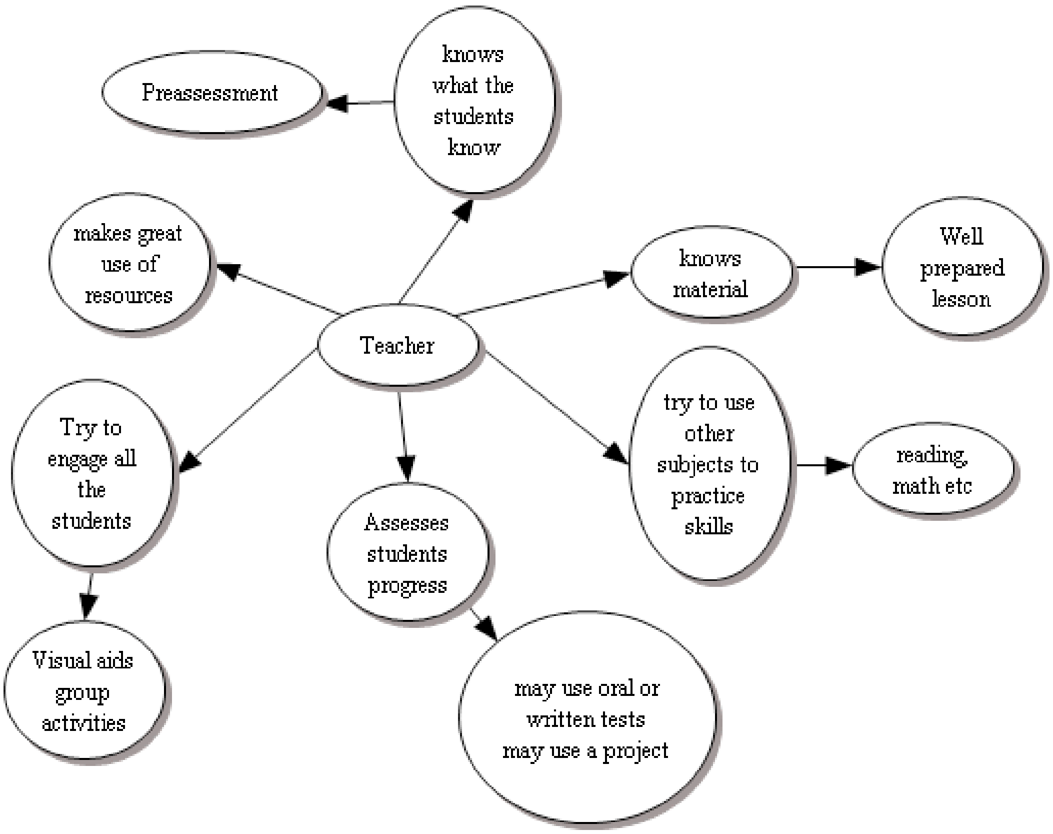


Figure 2b

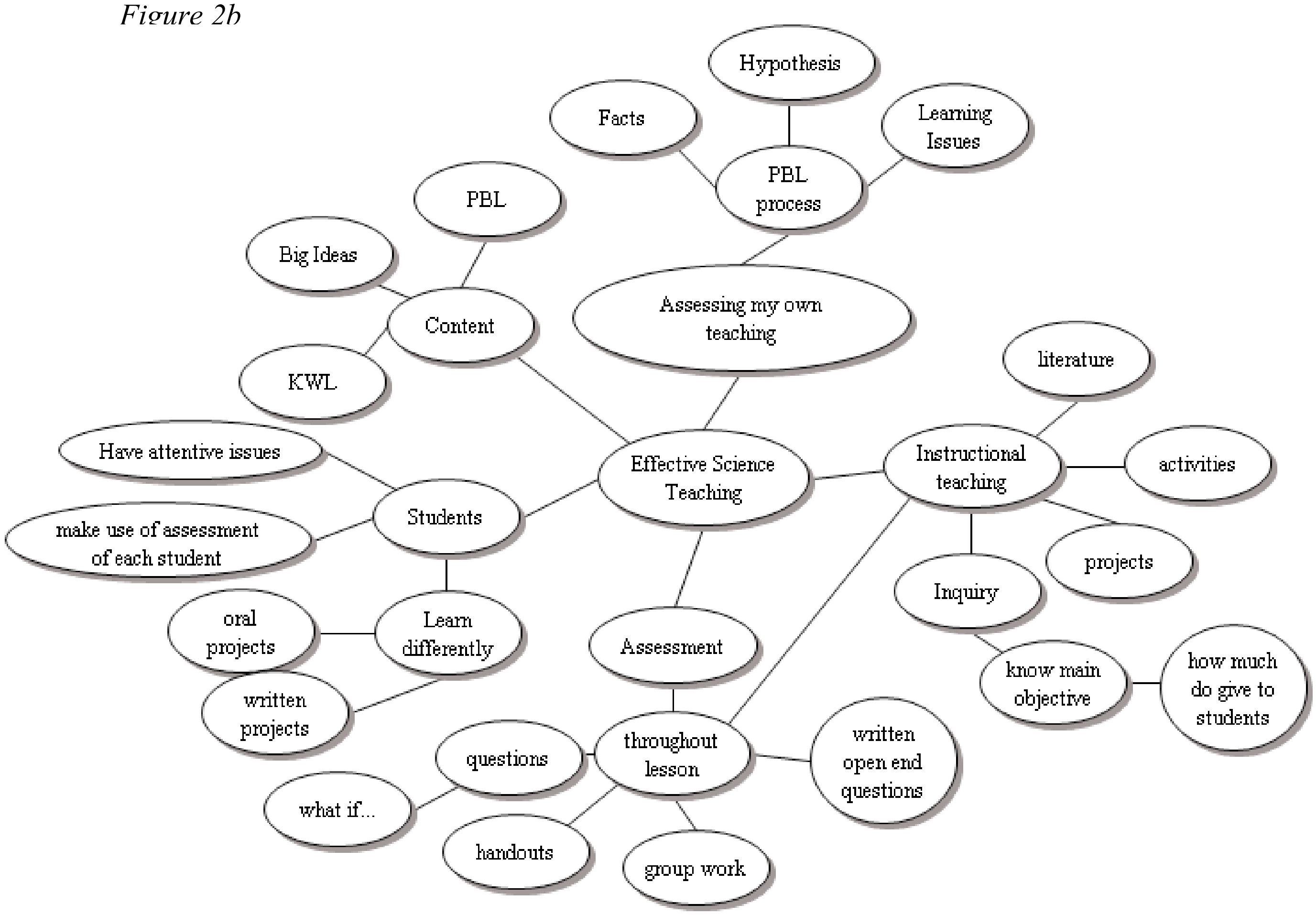


Table 1

PCK Map Coding Interrater Reliability

Item	Cronbach's Alpha	Correlation
I-Orientations	0.776	0.639
II-Curriculum Knowledge	0.748	0.599
III-Assessment	0.789	0.652
IV-Instruct. Strategies	0.663	0.498
V-Knowledge of Students	0.866	0.764

Table 2

Change in content knowledge

Group	Knowledge Gain (0-3) Mean (Std Dev)	Matched-pair t(21)	p	Cohen's d
Earth/Space (n=9)	0.33 (1.41)	0.71	.568	0.234
Physics (n=8)	1.25 (0.46)	7.64	.000	2.717
Biology (n=5)	-1.20 (.84)	-3.21	.099	-1.429
Overall (n=22)	0.32 (1.36)	1.10	.568	0.235

Table 3

Results for pre- post-PCK concept maps

Measure	Pre Score (0-3) Mean (Std Dev)	Post Score (0-3) Mean (Std Dev)	Matched-pair t(19)	P	Cohen's d
Orientations					
Constructivist	1.35 (0.75)	0.95 (0.69)	-2.18	0.210	-0.559
Conceptual Change	0.25 (0.55)	0.50 (0.89)	1.31	0.612	0.338
Inquiry	1.10 (0.91)	1.05 (0.95)	-0.22	0.906	-0.054
Hands-On/Activity Driven	1.00 (0.86)	0.65 (0.59)	-2.10	0.210	-0.476
Didactic	0.50 (0.69)	0.35 (0.59)	-0.77	0.906	-0.235
Curricular Knowledge					
Learning goals/big ideas	0.60 (0.68)	1.25 (0.72)	3.11	0.006**	0.930
Assessment	0.64 (0.38)	1.11 (0.65)	3.28	0.020**	
Students' knowledge	1.10 (0.64)	1.30 (0.80)	1.07	0.297	0.276
Students' scientific practices	0.20 (0.41)	0.50 (0.83)	1.55	0.274	0.460
Informs instructional decision	0.35 (0.59)	1.05 (0.89)	3.20	0.020**	0.931
Ongoing/embedded	0.90 (0.72)	1.60 (1.19)	2.57	0.057	0.713
Instruct. Strategies	0.90 (0.43)	0.86 (0.51)	-0.41	1.000	
Activity cycle	0.90 (0.64)	0.80 (0.77)	-0.70	1.000	-0.141
Consider student ideas	1.20 (0.77)	1.10 (0.91)	-0.46	1.000	-0.119
Multiple representations	1.20 (1.01)	0.95 (1.00)	-1.04	1.000	-0.250
Instructional pros and cons	0.05 (0.22)	0.40 (0.60)	2.33	0.217	0.775
Inquiry application	1.10 (0.85)	1.00 (0.92)	-0.46	1.000	-0.113
Motivating environment	0.95 (0.76)	0.90 (0.91)	-0.33	1.000	-0.060
Students	0.32 (0.37)	0.33 (0.42)	-0.25	0.804	
Knowledge of misconceptions	0.05 (0.22)	0.25 (0.55)	1.71	0.288	0.476
Connect to students' lives	0.85 (0.99)	0.60 (0.88)	-1.75	0.288	-0.2670
Student learning trajectories	0.05 (0.22)	0.05 (0.22)	2.70	0.056	0
# nodes	11.40 (6.44)	15.50 (7.52)	2.70	0.014**	0.585
# links	12.55 (7.22)	18.20 (10.04)	3.01	0.007**	0.646

** The mean difference in scores is statistically significant, p<.05

Figure Captions

Figure 1. Example of pre- and post- content knowledge concept maps

Figure 1a. Diana's pre-test content knowledge concept map

Figure 1b. Diana's post-test content knowledge concept map

Figure 2. Example of PCK pre- and post- concept maps

Figure 2a. Linda's PCK Pre-test concept-map

Figure 2b. Linda's PCK Post-test concept-map

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