Identifying shifts in TA's pedagogical content knowledge (PCK):

Outcomes of a "Scientific Teaching" course for biology graduate teaching assistants

at a large research university

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Among policy makers there is an ongoing discussion about the need to improve undergraduate education in science and engineering. Many reason that by improving undergraduate education, more science and engineering students will persist in these fields and fill the ongoing shortage of scientists and engineers that exist in the United States. This is important as many government positions in the United States are only available to citizens. Additionally, improving undergraduate education in the sciences will ensure that all students in higher education become scientifically literate. That is, they will be able to reason through scientific claims that are shared in the media (e.g., genetic engineering, personalized medicine).

One particular pathway for improving undergraduate education in the science fields is to reform undergraduate teaching. Publications from the National Academy Press conclude that undergraduate education should embrace (a) active learning environments, (b) fewer key concepts, and (c) cooperative learning groups (National Research Council [NRC], 1998, 2000, 2003). These methods give undergraduates an opportunity to build deep knowledge in certain areas, and it allows them to learn how to create learning communities.

Graduate Teaching Assistants (GTAs), who teach undergraduates, may be the most likely to adopt these recommended methods. Many higher education institutions employ GTAs for teaching undergraduate STEM courses including lectures, recitations, and laboratory classes. More importantly, GTAs, like new teachers, are just learning to teach. Just like new teachers, they need a solid preparation program that ensures they build their skills and knowledge in this area. With many undergraduate students being taught by GTAs, it is important to explore the

development of STEM knowledge for teaching by GTAs.

Over the past two decades, educational researchers have studied the development of one's knowledge to teach. This professional knowledge has been characterized as a way to turn content knowledge into learning (Grossman, 1990; Shulman, 1986; Shulman, 1987; Wilson, 1987). Studies in this area give insights into how the knowledge to teach develops in K-12 teachers. While the vast majority of studies have involved science teachers, fewer studies have focused on the development of this knowledge in GTAs.

This study is the first step in characterizing the knowledge of GTAs in learning to teach science. It specially looks at how the knowledge to learn how to teach science is developed by GTAs as they participate in a GTA teaching program. The development of this knowledge base among GTAs was documented through qualitative methods, which were selected specially to help answer the questions:

1) What are the ITAs' orientations toward teaching undergraduate biology during the "Scientific Teaching" course?

2) What are the shifts in knowledge in the areas of student understanding and instructional strategies of the biology ITAs during the "Scientific Teaching" course?

3) What were the barriers and bridges to building the ITAs' PCK?

The findings of the study will be used to: (1) inform the development of the Innovative TA program in SoLS, and (2) identify areas of curriculum modifications of the GTA teaching course.

Context- GTA teaching program

The Innovative TA program in the School of Life Sciences (SoLS) at Arizona State University was instituted in the fall semester of 2011 to improve undergraduate science teaching

and learning. Beyond the traditional number of teaching assistantships, additional GTAs (Innovative TAs) were made available to support instructors of upper-division undergraduate biology courses with large class sizes (≥ 80 students). To be assigned an ITA, biology faculty were required to submit proposals to the SoLS Associate Director of Undergraduate Programs, Dr. Miles Orchinik, describing the anticipated role(s) of the ITAs to enrich the learning environment (i.e., increase active learning, promote critical thinking, support writing in science). Specifically, the proposal had to indicate how the ITA would contribute to: (1) improving learning outcomes, (2) enhancing writing skills, (3) developing innovative tools, and (4) improving assessment of student understanding. Based upon the adequacy of the proposals and available funding, ITAs were assigned to large upper-division undergraduate biology courses.

All graduate students awarded an Innovative teaching assistantship must be knowledgeable about the content covered in their assigned course. Based upon the feedback received from faculty with ITAs during the fall semester, Dr. Orchinik arranged for the ITAs to receive education in the area of science teaching during the spring semester of 2012. Kathleen Hill, a science education doctoral student in the Mary Lou Fulton Teacher's College at ASU, was recruited to design and implement a 1-credit "Scientific Teaching" course.

Research Background

Research of GTA education programs

Creating effective GTA education programs is important to undergraduate science teaching. Recent studies have focused on identifying the elements of an effective GTA education program. Luft, Kurdziel, Roehrig, and Turner (2003) determined that a semester-long seminar for chemistry GTAs provided limited support for GTAs implementing inquiry-based strategies in

labs. Based upon their findings, they suggested that teaching strategies be discussed on a weekly basis. As an upcoming lab is discussed during the weekly staff meetings, supervisors should model the expected behavior of the GTAs in the classroom. They also recommended that GTAs observe an experienced GTA or staff member interact with students to demonstrate questioning strategies. Additionally, it was suggested that GTAs be encouraged to audio record their own teaching sessions with students and analyze their interactions.

Addy and Blanchard (2010) investigated the beliefs and practices of eight biology GTAs following a year-long training program consisting of a seminar course and a practicum course of peer teaching evaluations. They reported that the GTAs held a wide range of beliefs, however, their beliefs did not always match their teaching practices. Further,among GTAs with student-centered teaching beliefs, those that perceived increased control exhibited more reform-based practices during a lesson than those who did not report increased control."? Addy and Blanchard (2010) recommended that more training be provided which is designed to challenge teacher-centered beliefs. In addition, the GTAs should be allowed to observe models of student-centered instructional practices. Finally, Addy and Blanchard (2010) recommended that future studies of GTA programs include pre- and post-program data on GTAs in training.

Dotger (2011) conducted a study of four earth science GTAs who were provided training using a lesson study. The GTAs attended six three-hour seminars in which they received support through the stages of the lesson study. Dotger (2011) found that lesson study supported the "GTAs to begin thinking about rationales and purposes for teaching as they design instruction." She stated that GTAs would require additional lesson study cycles to develop sufficient science knowledge for teaching. Dotger also recommended that faculty have greater involvement in the training program.

Based upon recommendations from prior research, the semester-long training provided for GTAs in this current study at ASU included the modeling of innovative instructional strategies, engagements to challenge teacher-centered beliefs, and opportunities to develop a rationale for teaching.

Research in Teacher Development

A vast number of studies have been conducted regarding the development of teachers over time. Three important areas of science education research involve teachers' transitions in terms of professional concerns, formal professional development experiences, and professional knowledge development. Based upon studies of novice teachers, Fuller (1960, Fuller & Brown, 1975) put forth a concerns-based model of the developmental stages of concerns through which teachers move during their early career. This particular model has been used in many studies of pre-service and practicing teachers. Fuller's model includes three stages of novice teacher development: (1) concerns about self, (2) concerns about tasks/situations, and (3) concerns about impact on students. Countless numbers of professional development programs have been implemented to provide teachers with opportunities to further develop their professional skills. These programs have been designed to educate teachers about a wide variety of topics using a wide variety of techniques. One common finding involves the time spent in the professional development program. Supovitz and Turner (2000) report that a significant change in teacher practices came after 80 hours of professional development. Finally, Cochran-Smith and Lytle (1999) reviewed research regarding teacher practice and knowledge development. The findings of these studies reveal that teachers develop the specialized professional knowledge for teaching while they are engaged in practice.

PCK: A framework for GTAs' knowledge for teaching

Shulman (1986) introduced the concept of PCK as part of a model to understand science teachers' knowledge for teaching. He defined PCK as "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987). In science, PCK is the knowledge that teachers use to facilitate student understanding of the nature of science processes and science concepts. According to Grossman (1990), three knowledge domains contribute to the construction of PCK: content knowledge, pedagogical knowledge, and knowledge of the teaching context. Magnusson, Krajcik, and Borko (1999) proposed a science-specific model of PCK that identified four knowledge domains of PCK as knowledge of science curriculum, knowledge of students' understanding in science, knowledge of instructional strategies, and knowledge of assessment in science. The framework also included a teacher's orientation toward science teaching which influences and is influenced by the four knowledge domains. The PCK model illustrates that only developing knowledge of the science content is not sufficient for effectively teaching science. Knowledge of student learning, curriculum, instructional strategies, and assessment are also necessary for translating content knowledge into effective science teaching. A diagram of a simplified version of the model is presented in Figure 1 (Friedrichsen, Van Driel, and Abell, 2011).

The term "orientation" was originally defined by Anderson and Smith (1987) as four varying approaches to science teaching (activity-driven, didactic, discovery, and conceptual-change). Magnusson, Krajcik, and Borko (1999) defined an orientation as a "general way of viewing or conceptualizing science teaching". They identified nine different teaching orientations according to the goal of teaching science and the characteristics of instruction for each orientation. A teacher's orientation toward teaching influences and is influenced by the
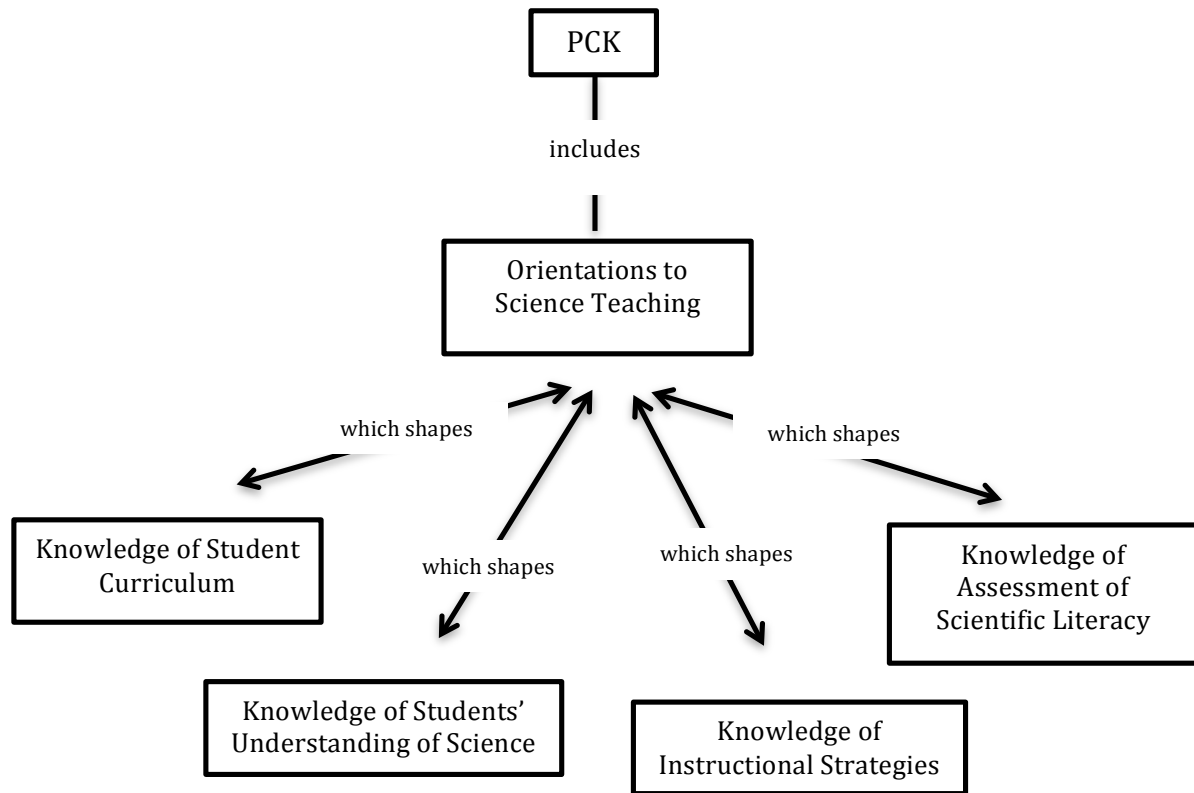
four knowledge domains.

Figure 1. PCK model for science teaching. Note: Adapted version from Magnusson, S., Krajcik, J. and Borko, H. (1999). Presented in Friedrichsen, P., Van Driel, & J.H., Abell, S.K., (2011). Taking a closer look at science teaching orientations, *Science Education*, *95*, 358-376.

According to Magnusson, Krajcik, and Borko (1999), teachers' knowledge of student understanding of science includes knowledge about how students learn science. This knowledge domain includes the requirements for learning science concepts, areas of learning difficulties, approaches to learning science, and naïve conceptions (Magnusson, Krajcik, and Borko,1999). Knowledge of instructional strategies includes knowledge of subject-specific teaching approaches and topic-specific strategies (Magnusson, Krajcik, and Borko,1999). Strategies that are subject-specific can generally be applied to science teaching such as learning cycles, inquiry-

oriented labs, and conceptual change strategies. Strategies that are topic-specific are methods used in teaching a particular topic within a subject of science such as models, demonstrations, and case studies.

Knowledge of science curriculum refers to knowledge of (a) mandated goals and objectives and (b) specific curriculum programs as well as the activities and materials included in the curriculum. Knowledge of assessment of science literacy refers to teachers' knowledge of how to assess science understanding. This knowledge domain includes what to assess in science and appropriate methods of assessment.

A list of elements to further define the five components of PCK were developed by Weizman, Covitt, Koehler, Lundeberg and Oslund (2008). The specific elements for orientations toward teaching and the four knowledge domains are presented in Table 1. Given that the semester-long training provided for the GTAs focused on challenging teacher-centered orientations toward teaching and developing knowledge of student learning and instructional strategies, elements identified for these three components of PCK were used to characterize the GTAs' orientations toward teaching and identify shifts in their knowledge of student understanding and instructional strategies.

The "Scientific Teaching" course design

Biology 594, "Scientific Teaching", was a semester-long course designed to support ITAs in developing science knowledge for teaching at the undergraduate level. The curriculum focused on two knowledge domains that influence PCK: student understanding in science and reformed instructional practices. The course was in part based upon the workshops presented in *Scientific Teaching* developed by The Wisconsin Program for Scientific Teaching (supported by the Howard Hughes Medical Institute Professors Program) for current and future biology faculty.

Table 1. Categories and indicators for PCK analysis presented in Weizman, A., Covitt, B. A., Koehler, M. J., Lundeberg, M. A., Oslund, J. A., Low, M. R., Urban-Lurain, M. & Eberhardt, J. (2008). Measuring teachers' learning from a problem-based learning approach to professional development in science education. *The Interdisciplinary Journal of Problem-based Learning, 2,* 29–60.

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 applications
    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)

A list of topics along with associated readings, class engagements and targeted knowledge domains are presented in Table 2.

Kathleen Hill served as the lead instructor of the "Scientific Teaching" course, bringing the perspective of a former secondary science teacher and current science education doctoral

student. The assigned weekly readings provided a theoretical background of science teaching for the ITAs. Based on the recommendations of prior research, class engagements were designed to challenge teacher-centered beliefs, model innovative teaching strategies, and provide opportunities for ITAs to develop a rationale for teaching science.

A number of class sessions were designed to challenge ITAs' teacher-centered beliefs about undergraduate science teaching by confronting their misconceptions about student learning. For example, during the session on constructivism, the ITAs were asked to create a concept map for the general topic of "science education". Following the completion of the concept maps, a group discussion was facilitated through a series of questions as follows:

1. *If I [the course instructor] were to create a concept map of science education, do you believe that my concept map would be structured differently from your concept map? Why or why not?*

2. *If I were to display my concept map to you using the projector, do you think that it would be beneficial to your learning about science education? Why or why not?*

3. *If you were required to recreate your own concept map a week from today, do you think that your product would look similar to your original concept map? Would this be a difficult exercise? Why or why not?*

4. *If you were required to recreate my concept map a week from today, do you think that your product would look similar to my concept map? Would this be a difficult exercise? Why or why not?*

5. *How are the cognitive processes involved in recalling your own concept map different from the cognitive processes involved in recalling my concept map? Describe the mental steps that you would take in order to accomplish recalling each of the maps.*

Then, the ITAs discussed the learning environments that they experienced as undergraduate students and observed as GTAs that support knowledge construction.

The engagements in the classes were also designed to model the use of innovative instructional strategies. The ITAs learned to construct concept maps and were provided examples of using concept maps in teaching science. Guiding questions were provided to ITAs for more challenging reading assignments and were used to initiate class discussions. The ITAs were often involved in Think-Pair-Share and small group discussions during which the instructor would visit groups to listen to ITA responses and ask guiding questions. The ITAs were required to work in small groups to develop a detailed lesson plan for a topic of their choice in biology. This was a larger project that spanned several weeks of the course. Peer reviews of the lesson plans were provided following group presentations using the project rubric. Instructor feedback was also provided. Smaller group projects were also assigned during the classes such as evaluating lesson plan designs and rewriting assessment items. Whole-group discussions were facilitated by the instructor which provided the modeling of effective questioning techniques. The ITAs were encouraged to use personal examples of interactions with undergraduate students to explain their understanding of student learning and formulate questions.

The weekly classes were also designed to provide opportunities for ITAs to develop a rationale for teaching science. Individual classes provided engagements developed around a particular topic. Following the in-class engagement, the ITAs worked in small groups to incorporate elements of the topic into their lesson plan projects in support of student learning. For example, during the session on formative assessment, ITAs discussed opportunities for ongoing assessment in the classroom setting and appropriate instructional decisions based upon feedback from students. Based upon the group discussion, the ITA groups reviewed their lesson

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Table 2. Topics covered in Biology 594, associated readings, class engagements, and targeted knowledge domains.

Topic	Reading(s)	Class Engagement	Targeted Knowledge Domain
Constructivism Concept Maps	Chapter 1 in *Scientific Teaching* *The Theory Underlying Concept Maps and How to Construct Them*	Create a concept map of "Science Education" Group discussion of learning in science	Student Learning
Goals of Undergraduate Science Education Inquiry	*Vision and Change in Undergraduate Biology Education: A Call to Action*	Small and whole group discussion of goals of undergraduate biology education Small group evaluation and classification of labs on inquiry continuum	Curriculum
Conceptual Change	Hewson, P. W., Beeth, M. E., & Thorley, N. R. (1998). Teaching for conceptual change.	Draw a model of how they learn in science T-P-S about how they learn in science Discussion of how people learn	Student Learning Instructional Strategies
Conceptual Change	Chapter 2 in *Scientific Teaching*	Small and whole group discussion of the status of ideas and naïve conceptions (photosynthesis, evolution) for undergraduate students Group evaluation and discussion of student work products as evidence of student understanding or misunderstanding	Student Learning
Active Learning and 5E Lesson Plan	Chapter 5 in *Scientific Teaching*	Whole group discussion addressing the question: What is active learning? and examples of active learning strategies Small group discussions of lesson plan project	Student Learning Instructional Strategies
5E Lesson Plans		Small group presentations of lesson plan project and peer-review of lesson plans using rubric	Curriculum Student Learning Instructional Strategies
Confronting Realities of Active Learning	Chapter 5 in *Scientific Teaching*	Group evaluation and discussion of videos including undergraduate instructors and students engaged in active learning environments	Assessment Student Learning Instructional Strategies
Formative Assessment	Chapter 3 in *Scientific Teaching*	Small group discussions of opportunities for ongoing assessment using classroom scenarios and appropriate instructional decisions based upon student responses	Assessment Student Learning Instructional Strategies
Student Motivation		Whole group discussion of model of Self-Determination Theory Small group work to develop a lab (with microscopes) using the elements of Self-Determination Theory to increase student motivation	Student Learning Instructional Strategies Assessment
Summative Assessment	Krathwohl, D. R. (2002). A revision of bloom's taxonomy: An overview.	Small and whole group evaluation and discussion of multiple-choice questions and assignment rubrics using revised Bloom's taxonomy Small group work to develop multiple-choice questions and rubrics	Assessment

Then, the ITAs discussed the learning environments that they experienced as undergraduate students and observed as GTAs that support knowledge construction.

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The weekly classes were also designed to provide opportunities for ITAs to develop a rationale for teaching science. Individual classes provided engagements developed around a particular topic. Following the in-class engagement, the ITAs worked in small groups to incorporate elements of the topic into their lesson plan projects in support of student learning. For example, during the session on formative assessment, ITAs discussed opportunities for ongoing assessment in the classroom setting and appropriate instructional decisions based upon feedback from students. Based upon the group discussion, the ITA groups reviewed their lesson

plan projects and identified opportunities within the lesson for formative assessment to take place. As part of their final reflection assignments, the ITAs explain how the lesson plan allowed for an instructor to make formative assessments of students' understanding and describe the anticipated interactions between the teacher and the students that support knowledge construction.

Emphasis each week was on the practical application of topics covered in the classes to teaching science in a large research university setting. These topics focused primarily in developing the ITAs' knowledge in the areas of student understanding in science and instructional strategies.

Methods

This study was designed as a mixed methods study involving both qualitative and quantitative data. The ITAs created concept maps at the beginning and end of the "Scientific Teaching" course. The pre-concept maps and post-concept maps were quantized using a scoring rubric. The resulting quantitative data was used to generate descriptive statistics regarding the ITAs' change in knowledge of student understanding and instructional strategies. The qualitative data was obtained from the ITAs' responses to an open-ended questionnaire through an inductive analysis of the text. Themes that emerged from the data were analyzed in an iterative process to identify patterns that address the research question regarding orientations toward teaching (Creswell & Plano Clark, 2010). The qualitative and quantitative data sets were merged to identify the barriers and bridges to the ITAs' development of PCK.

Participants

The participants in the study include a purposeful sample of ten "Innovative TAs" in the biology department of a large research institution. The names of the ITAs have been replaced by

pseudonyms for the purpose of protecting their anonymity. The sample included six female

biology ITAs and four male ITAs. All Innovative TAs are doctoral-level graduate students,

however, they come from varied fields of expertise within the discipline of biology ranging from

ecology to cellular and molecular biology. The participants also differ in their amounts and types

of teaching experience. Three of the ITAs had previous experience teaching at the secondary

level. Table 3 outlines their experience as ITAs and teaching at the K-12 level.

Table 3. Participant quantities and types of prior teaching experience.

Name*	Gender	Prior K-12 teaching (years)	Prior GTA experience (semesters)
Bruce	M	0	over 9
Ellen	F	0	over 9
Judith	F	1	8
Scott	M	3	6
Danielle	F	0	4
Patrick	M	0	4
Rose	F	0	3
Annie	F	0	2
Joe	M	1*	2
Laura	F	0	1

* pseudonym   ** experience in after-school program

Given the small sample size (n = 10), the findings of this study are not considered to be

generalizable to a large population of graduate assistants.

Research setting

The study took place over a 4-month period during the spring semester at a large research

university located in the southwestern region of United States. This was the first semester that

the life sciences unit offered the "Scientific Teaching" course designed specifically for the

Innovative TAs. During the semester, the ITAs were active teaching assistants in upper-division

undergraduate biology courses. Given that the data were collected at the beginning and end of

the "Scientific Teaching" course, the findings cannot be extended beyond the timeframe of the

study.

Data Collection and Analysis

Data were collected using concept maps and open-ended questionnaires. The open-ended

questionnaire was designed to collect information primarily in the area of the ITAs' orientation

toward teaching. The instrument was used to capture information about the types and amounts of

the ITAs' previous teaching experience, their reasons for being an ITA, a detailed description of

their responsibilities as an Innovative TA during the spring semester, and detailed descriptions of

their direct interactions with students. Many of the questions posed were extremely general to

allow the ITAs to report the information they deemed to be important. The questions included:

1. *How many semesters have you taught at the undergraduate level?*

2. *How many years have you taught at the K-12 level?*

3. *Why are you a TA?*

4. *What were your primary responsibilities as a TA? Please describe in detail.*

5. *What were some additional responsibilities as a TA? Please describe in detail.*

6. *Did you have an opportunity(ies) to work directly with students in the course? If yes, how*

   often did this occur during the semester? Please describe the interaction(s) in detail.

The questionnaire responses provided by the ITAs were coded to identify themes

regarding their reported interactions with students during the course. The themes were used to

classify each ITA in terms of their orientation towards teaching. The emergent themes were

compared to the five orientations toward teaching listed in Table 1. Given that the open-ended

questions were general in nature, information gathered from the questionnaire regarding the

ITAs' orientations toward teaching and specific instructional practices may be limited.

The ITAs created pre- and post-concept maps for the general topic of "science education" at the beginning and end of the teaching course, respectively. Concept maps have been used as an assessment tool in educational research (Morine-Dershimer, 1989; Gess-Newsome & Lederman, 1993). More recently, Hay, Kinchin, and Lygo-Baker (2008) discussed using concept maps to make understandings visible including prior knowledge, the learning of new concepts, and the links between existing and new knowledge structures. Although claims have been made that concept maps may reflect internal cognitive structures, it has not been established that the constructed diagrams are literal depictions of knowledge stored in the memory (Baxter and Lederman, 1999). In this study, the use of concept maps is limited to identifying any change in knowledge during a semester-long "Scienctific Teaching" course. It is not intended to assess any permanent changes in knowledge structures, but is used to identify short term shifts which may or may not persist over time.

The pre- and post-concept maps were analyzed separately based upon the indicators for knowledge of student understanding and knowledge of instructional strategies listed in Table 1. Using the method employed by Weizman, Covitt, Koehler, Lundeberg and Oslund (2008), the concept maps were quantized by assigning scores based upon a scale of 0 to 3 for the targeted components of PCK – knowledge of student learning and knowledge of instructional strategies. The scoring system is presented in Table 4. Individual pre-concept maps were assigned a score for each of the targeted PCK knowledge domains: student understanding in science and instructional strategies. The two scores were then averaged to produce an overall score for the pre-concept. The same procedure was followed for the post-concept map. The differences in the average scores between the pre- and post-concept maps were calculated.

Table 4. Scoring system for pre- and post-concept maps presented in Weizman, A., Covitt, B. A., Koehler, M. J., Lundeberg, M. A., Oslund, J. A., Low, M. R., Urban-Lurain, M. & Eberhardt, J. (2008). Measuring teachers' learning from a problem-based learning approach to professional development in science education. *The Interdisciplinary Journal of Problem-based Learning, 2,* 29–60.

Score	0	1	2	3
Level of explanation of component of PCK	The topic is not present.	The topic was just mentioned.	The topic was partly elaborated.	The topic was clear and explained.

Findings

The findings that correspond with the research questions are discussed here in.

Question 1: What were the ITAs' orientations toward teaching biology during the "Scientific Teaching" course?

The questionnaire responses describing the ITAs' interactions with students were coded, and emergent themes were used to classify the ITAs' orientation toward teaching. The ITAs were asked to describe their interactions with students in detail.

Annie served as an ITA during the 2011-2012 academic year with no prior experience as a graduate teaching assistant. Although Annie did not have direct interactions with students as an ITA in the spring, her response described the nature of her interactions with students as an ITA during the fall semester prior to the teaching course. Annie described these interactions as follows:

> "I worked with the students directly every week during recitation. At first I was
>
> primarily lecturing and taking questions from students. Later in the semester I
>
> had them work in groups to solve problems; I would walk around to the groups
>
> and ask them questions about the problems, and take questions from them. I

> *would also pick individuals or groups to explain how to solve the problems to the*
>
> *class."*

Although her early interactions exhibited a didactic orientation, her later interactions were more consistent with a constructivist orientation toward teaching biology. Based upon her response, she was classified as having a constructivist orientation.

Bruce reported having over nine semesters of experience as a graduate teaching experience in SoLS. As an ITA, he was provided with the opportunity to work directly with students in lecture and in the laboratory setting. Bruce described his interactions with students as follows:

> *"I interact with students in the lecture as well as the lab that meets two times a*
>
> *week. The lecture interaction involved me presenting lecture material as well as*
>
> *facilitating small group discussions. The laboratory section allowed me to work*
>
> *with students on a 1 on 1 basis as well as assist the lead lab TA. I lectured*
>
> *roughly 50% of the time and was present in lab 50% of the time."*

 With his interactions primarily involving lecturing to students, Bruce was classified as having a didactic orientation toward teaching biology.

Results of analyzing the ITAs' questionnaire responses are presented in Table 5. Based upon the emergent themes derived from the reported interactions with students, the ITAs were classified in two of the five orientations. Six of the ITAs' were classified as having a didactic orientation while four were classified as having a constructivist orientation toward teaching.

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Table 5. ITAs orientations toward teaching along with reported interactions with students, and roles of the ITA assigned by faculty.

Name	Orientation toward teaching	Reported interactions with students	Reported role of ITA designated by faculty
Scott	Constructivist framework	• Led small group discussion in weekly recitation sessions using questioning techniques • Wrote extensive positive and negative feedback on drafts of large writing assignments • Met with students in one-on-one to review feedback on writing assignments • Met with students in one-on-one tutoring to discuss course concepts	• Led scheduled weekly recitation sessions • Developed lesson plans for the recitations which focused on course readings • Reviewed drafts of written assignments and provided substantial feedback • Supervised student projects • Graded papers • Led final exam review • Held office hours for tutoring
Annie	Constructivist framework	Prior GTA Experience (not ITA; prior to course) • Started out lecturing in weekly recitations • Moved to having students work in small groups • Visited each group to assess understanding and pose questions to guide the discussion • Had students present solutions to class • Facilitated peer-review of presented solutions ITA Experience • Answer questions before and after lecture • Grade exam essay questions and papers	• Graded papers and exam essay questions • Held office hours for tutoring
Joe	Constructivist framework	• Led small group discussions of course honors section using questioning techniques • Led exam review sessions guided entirely by student questions – facilitated using questioning techniques	• Led course honors discussion group • Developed lesson plans for honors discussion group • Led exam review sessions • Led break-out discussions sessions • Designed lecture clicker questions
Judith	Constructivist framework	• Led discussions in recitations in which students work on problems posed in lecture • Had students work in small groups to develop solutions • Facilitated discussions that focused on the concepts rather than arriving at the correct answer • Met with students one-on-one to answer questions pertaining to the homework	• Led scheduled weekly recitations sessions • Attended lecture • Prepared quizzes • Graded homework and projects • Held office hours • Proctored exams

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Name	Orientation toward teaching	Reported interactions with students	Reported role of ITA designated by faculty
Danielle	Didactic	• Led recitations by answering student questions • Met with students one-on-one to discuss projects and assignments • Reviewed concepts covered in lecture • Discussed grading rubrics and graded assignments to explain missed material	• Led unscheduled recitations to address student questions • Develop and grade projects • Develop homework, quizzes, and extra credit assignments • Grade assignments • Proctor exams
Rose	Didactic	• Answered questions posed by small groups during discussions of content presented in assigned readings • Answered questions posed by small groups during discussions of writing assignments	• Attend all lectures • Circulate during small group discussions held in lecture to answer questions • Write questions for quizzes and tests • Grade all writing assignments
Patrick	Didactic	• Delivered a lecture to the class • Answered student questions and had short discussions on day of lecture presentation • Met with students one-on-one to answer questions about homework assignments • Answered student questions via e-mail	• Deliver one presentation during lecture • Hold office hours to address student questions in person or via e-mail • Grade homework
Bruce	Didactic	• Deliver lecture material to the class • Facilitated small group discussions during lecture • Answer student questions and had short discussions with students before and after lecture periods and during labs	• Develop lecture material • Develop exams • Assist with lab • Facilitate field trips
Ellen	Didactic	• Answered student questions in break-out sessions and review sessions • Answered student questions at the end of lecture • Met with students one-on-one to answer student questions • Answered student questions via e-mail	• Led unscheduled break-out sessions • Led unscheduled review sessions • Assist in designing writing assignments • Grade assignments • Proctor exams
Laura	Didactic	• Answered student questions at the end of lecture	• Attend lectures • Grade assignments and tests

Question 2: What are the shifts in the ITAs' knowledge of student learning and knowledge of instructional strategies during the "Scientific Teaching" course?

The scores from the pre- and post-concept maps were used to identify shifts in ITAs' knowledge of student understanding and knowledge of instructional strategies. Score results for the two targeted knowledge domains are presented in Figure 2.
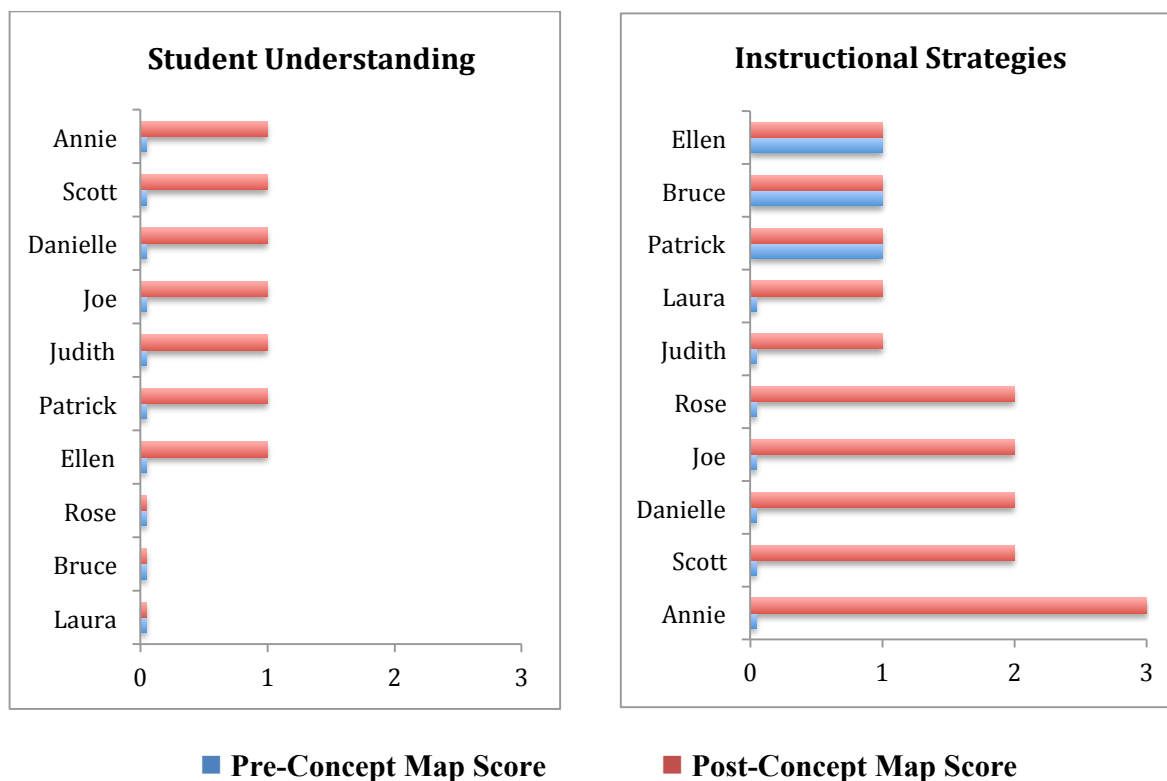

Figure 2. Pre- and post-concept map scores for knowledge of student understanding and knowledge of instructional strategies along with score differences.

The pre-concept maps revealed that none of the ITAs related student understanding to the general topic of "science education" (score = 0 out of 3). At the conclusion of the teaching course, seven of the ten ITAs mentioned student understanding on the post-concept map (score = 1 out of 3). The three remaining ITAs did not mention student understanding on the post-concept

map (score = 0 out of 3). During the teaching course, the ITAs had little to no positive shifts in the knowledge domain of student understanding.

On the pre-concept map, seven of the ITAs did not include instructional strategies (score = 0 out of 3) while three of the ITAs mentioned instructional strategies (score = 1 out of 3). At the end of the teaching course, five ITAs mentioned instructional strategies (score = 1 out of 3), four partly elaborated instructional strategies (score = 2 out of 3), and one clearly explained instructional strategies (score = 3 out of 3). In comparison to the shifts in knowledge of student understanding, five of the ITAs had greater positive shifts in their knowledge of instructional strategies (pre- and post-concept map score differences = 2 or more). The other five ITAs, which included those who originally mentioned instructional strategies on the pre-concept map, had little to no positive shift in the area of instructional strategies (score differences = 1 or less).

The calculated score differences for both knowledge domains were averaged to generate an overall average score. These averages are included in Table 6.

Table 6. Post- and pre-concept map differences and overall score average.

Name	Average Concept Map Scores		
	Post - Pre Difference Student Understanding	Post - Pre Difference Instructional Strategies	Avg. Post –Pre Differences
Bruce	0	0	0
Ellen	1	0	0.5
Patrick	1	0	0.5
Laura	0	1	0.5
Judith	1	1	1
Rose	0	2	1
Joe	1	2	1.5
Danielle	1	2	1.5
Scott	1	2	1.5
Annie	1	3	2

Following the "Scientific Teaching" course, four of the ITAs had positive shifts in their PCK (average differences greater than 1.5), however, six of the ITAs had little to no shift in their PCK.

Question 3: What were the bridges and barriers to building the ITAs' PCK?

In addressing this research question, we merged together the qualitative data and quantitative data along with demographic information. The ITAs' orientations toward teaching were compared to the overall average shift in PCK. In addition, demographic data was included in the analysis which illuminated bridges and barriers to the ITAs' building PCK. On the open-ended questionnaire, the ITAs reported their number of semesters of previous experience as an ITA, their reasons for being an ITA, and the ITA roles assigned to them by their faculty mentors.

Figure 3 includes a plot of number of the ITAs' total number of semesters as a graduate teaching assistant with the overall average differences between the pre- and post-concept map scores. The results indicate that the ITAs with more prior experience had lower positive shifts in PCK during the teaching course. The ITAs with less experience as a GTA had varied shifts in their PCK. In addition, three of the four ITAs determined to have a constructivist orientation toward teaching were among those that had the greatest positive shifts in PCK.

Scott, Annie, and Joe

Scott, Annie, and Joe reported that their primary reason for being an ITA was to gain experience teaching. In addition, these ITAs were assigned roles that allowed them to have frequent direct interaction with students independent of their faculty mentor. Scott and Annie had regularly scheduled weekly meetings with students during recitation. Joe also met with students directly, however, the dates and times of the meetings were irregular over the semester. All three ITAs reported having interactions with students consistent with the constructivist orientation toward
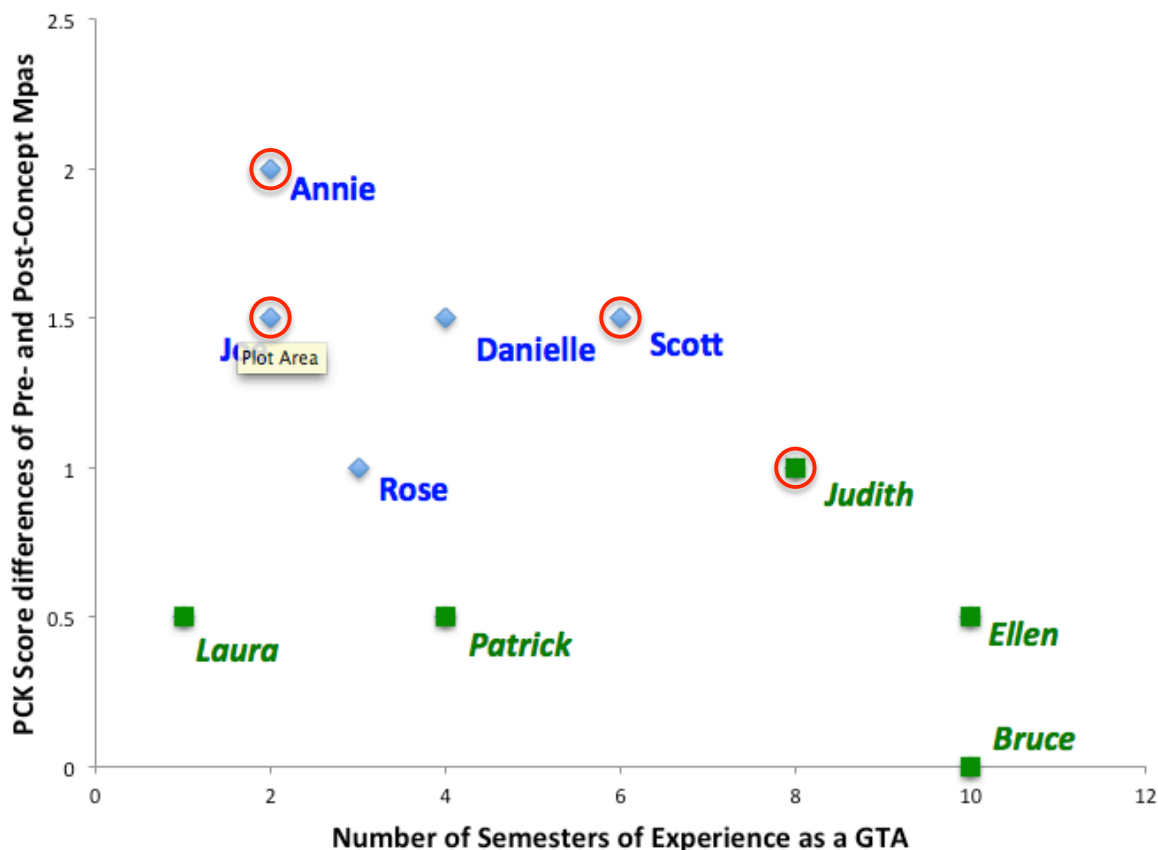
Figure 3. Placement of GTAs on chart displaying score differences for the concept maps, number of semesters as a GTA, reported interactions with students as an ITA, and reported purpose for being an ITA.

◆ **Blue names** = denotes participant being an ITA for teaching experience
● *Green italicized names* = denotes participant being an ITA primarily for funding
○ **Symbol** = denotes participant reported interactions with students consistent with constructivist orientation toward teaching

teaching. In comparing the overall PCK score differences, Scott, Annie, and Joe had greater shifts in their PCK than nearly all of the other ITAs.

Danielle and Rose

Danielle and Rose also reported being an ITA to gain experience in teaching. They had

similar levels of prior experience being graduate teaching assistants, and both were classified as having a didactic orientation toward teaching. However, the ITA roles assigned to them by their mentor faculty were different. Danielle had more opportunities to work directly with students. These meetings were not regularly scheduled, however, Danielle met with the students independent of her faculty mentor. Rose's interactions with students were extremely limited by her assigned role as an assistant during the faculty-led lectures. She only worked directly with students during small group work which consisted of her answering questions posed by the students.

Judith, Patrick, Bruce, Ellen, and Laura

Five of the ten ITAs – Judith, Patrick, Bruce, Ellen, and Laura – reported being an ITA for funding purposes without making mention of gaining teaching experience. Three of the ITAs reported the desire to be funded as a research assistant. Although the five ITAs varied in their levels of prior GTA experience, they made little to no positive shift in their PCK during the teaching course.

These ITAs were assigned a variety of roles as ITAs that resulted in varied levels of direct student contact. Based upon their reported interactions with students, four of the five ITAs were classified as having a didactic orientation toward teaching. In contrast, Judith was classified as having a constructivist orientation toward teaching. As an ITA with eight semesters of GTA experience, she was provided with weekly scheduled opportunities to work with students independent of her faculty mentor. In her questionnaire response, she explained that her faculty mentor instructed her to engage in teaching practices that supported students to develop more conceptual knowledge rather than focusing on arriving at a right answer in working problems.

Judith reported that she found this approach to teaching to be very difficult.

With over nine semesters of GTA experience, Bruce and Ellen also had opportunities to work directly with students in a classroom setting independent of their faculty mentor. Both reported having interactions with students that were consistent with a didactic orientation toward teaching. Patrick and Laura were extremely restricted in their interactions with students. Patrick was assigned to deliver a single lecture to the class along with answering student questions during office hours. Laura occasionally answered student questions at the end of faculty-led lectures, however, her primary function was to grade assignments and tests.

Discussion and Conclusions

This pilot study sought to characterize the teaching orientations and identify shifts in knowledge of teaching for ten ITAs during a "Scientific Teaching" course. ITA self-reports of interactions with students revealed that a majority had a didactic orientation toward teaching involving a teacher-centered approach. The concept maps indicated that the ITAs increased their knowledge in the area of instructional strategies more than in the area of student understanding. Based on the concerns-based model of teacher development, these findings indicate that the ITAs were primarily concerned about the tasks of the teacher and the student, and did not transition to thinking about students during the course (Fuller, 1960, Fuller & Bown, 1975). The "Scientific Teaching" course provided by SOLS to the ITAs was limited to the ten contact hours with the instructor and fellow ITAs. As a minimum of 80 hours of professional development are needed before changes are found in teacher practices, the ten hours in the "Scientific Teaching" course was not sufficient to produce significant changes in the GTAs' teaching practices (Supovitz and Turner, 2000).

The barriers and bridges to the ITAs building their PCK were also investigated in the

study. The assigned roles of the ITAs were decided by the course faculty members, and these roles varied between ITAs. Some were responsible for leading weekly recitations, others lectured and held offices hours, and others served primarily as graders. Scheduled direct interactions with students that were independent of the mentor professor served as the primary support to ITAs building their PCK. These settings provided ITAs with regular opportunities to implement reformed teaching practices and receive feedback from students. Those ITAs with restricted interactions with students had little to no PCK development. This is consistent with educational research reporting that teachers build their knowledge when they are engaged in practice (Cochran-Smith, M. & Lytle, S. L., 1999).

Prior experience as a GTA also influenced their knowledge development. The ITAs with the largest increase in their PCK had lower levels of experience whereas those with higher levels made little to no gains. In addition, the ITAs' motivation for being an Innovative TA was a factor. Those ITAs with the desire to develop their teaching practices had larger increases in their PCK than those who elected to be an Innovative TA for funding purposes.

The findings of this pilot study offer important information for the development of the Innovative TA program in SoLS. The program would better support ITAs by initiating teaching early in TA experience. To facilitate ITAs moving from thinking about what students are doing to how students are learning, SoLS could ensure that assigned ITA-roles provide structured opportunities to work directly with students and to practice making use of innovative teaching strategies. Building a community of faculty and graduate students that values teaching would support the ITAs in seeking to improve their teaching practices. As part of a community that values teaching, the ITA program would serve to promote GTA assignments as opportunities for developing teaching skills and diminish the view of the position as being a source of funding.

Additionally, SoLS should seek to build a strong program that provides additional teaching courses and support through the GTA experience, and rewards ITAs for completing the program by providing appropriate incentives such as a graduate teaching certificate.

References

Addy and Blanchard (2010). Addy, T. M., & Blanchard, M. R. (2009). The problem with reform from the bottom up: Instructional practices and teacher beliefs of graduate teaching assistants following a reform minded university teacher certificate programme. *International Journal of Science Education, 32*(8), 1045 – 1071.

Baxter, J.A. & Lederman, N.G. (1999). Assessment and measurement of pedagogical content knowledge. In J. Gess-Newsome, and N.G. Lederman (Eds.) *Examining pedagogical content knowledge*. Boston: Kluwer Academic Publishers.

Brewer, C. & Smith, D., *Vision and Change in Undergraduate Biology Education: A Call to Action.* Washington, DC (2011).

Cochran-Smith, M., & Lytle, S. L. (1999). The teacher research movement: A decade later. *Educational Researcher, 28*(7*),* 15-25.

Creswell, J. W., & Plano Clark, V. L. (2010). *Designing and conducting mixed methods research*. Thousand Oaks, CA: SAGE.

Dotger, S. (2011). Exploring and developing graduate teaching assistants' pedagogies via lesson study. *Teaching in Higher Education, 16*(2), 157-169.

Fuller, F. F. (1969). Concerns of teachers: A developmental characterization. *American Educational Research Journal*, 6, 207–226.

Fuller, F. F. & Bown, O.H. (1975). Becoming a teacher. In: K. Ryan (Ed.), *Teacher education* (74th Yearbook of the National Society of Education, pp. 25–52). Chicago: University of Chicago Press.

Gess-Newsome, J. & Lederman, N. G.: 1993, 'Preservice Biology Teachers' Knowledge Structures as a Function of Professional Teacher Education: A Year-Long Assessment', *Science Education, 77*(1)**,** 25–45.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Handelsman, J., Miller, S. & Pfund, C. (2007). *Scientific Teaching* (The Wisconsin Program for Scientific Teaching). New York: W. H. Freeman.

Hay, D, B., Kinchin, I.M., & Lygo-Baker, S. (2008). Making learning visible: the role of concept mapping in higher education. *Studies in Higher Education*, 33(3), 295-311.

Hewson, P. W., Beeth, M. E., & Thorley, N. R. (1998). Teaching for conceptual change. In B. J. Fraser & K. G. Tobin (Eds.), International handbook of science education (pp. 199 – 218). Dordrecht, The Netherlands: Kluwer.

Krathwohl, D. R. (2002). A revision of bloom's taxonomy: An overview. *Theory into Practice, 41*(4), 212-218.

Luft JA, Kurdziel JP, Roehrig GH, Turner J. (2004). Growing a garden without water: Graduate teaching assistants in introductory science laboratories at a doctoral/research university. *Journal of Research in Science Teaching, 41*, 211-233.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowl- edge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95 – 132). Dordrecht, The Netherlands: Kluwer.

Morine-Dershimer, G. (1993). Tracing conceptual change in preservice teachers. *Teaching and Teacher Education, 9,* 15–26.

Novak JD and Cañas AJ, *The Theory Underlying Concept Maps and How to Construct Them.* 2006, Florida Institute for Human and Machine Cognition: Pensacola, FL.

NRC (1998). *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology*, Washington, DC: National Academies Press. www.nap.edu/catalog.php?record_id6453 (accessed April 4, 2012).

NRC (2000). *How People Learn: Brain, Mind, Experience, and School: Expanded Edition*, Washington, DC: National Academies Press. www.nap.edu/catalog.php?record_id9853 (accessed April 4, 2012).

NRC (2003). *Evaluating and Improving Undergraduate Education in Science, Technology, Engineering, and Mathematics*, Washing- ton, DC: National Academies Press. www.nap.edu/catalog.php?record_id10024 (accessed April 4, 2012).

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1 – 21.

Supovitz,J. A., &Turner,H. M.(2000).The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching*, *37*(2), 963-980.

Weizman, A., Covitt, B. A., Koehler, M. J., Lundeberg, M. A., Oslund, J. A., Low, M. R., (2008). Using concept maps to measure changes in teachers' learning from a problem- based learning approach to professional development in science education. *The Interdisciplinary Journal of Problem-based Learning, 2*(2), 29-60.

Wilson, S. M., Shulman, L. S., & Richert, A. (1987). 150 different ways of knowing: Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring teachers' thinking* (pp. 104–124). Sussex: Holt, Rinehart & Winston.