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Applying a Cognitive-Affective Model of Conceptual Change to Professional Development

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Abstract This study evaluated Gregoire's (2003) Cognitive–Affective Conceptual Change model (CAMCC) for predicting and assessing conceptual change in science teachers engaged in a long-term professional development project set in a large school district in the southwestern United States. A multiple case study method with data from three teacher participants was used to understand the process of integrating and applying a reform message of inquiry based science teaching. Data sources included: responses to example teaching scenarios, reflective essays, lesson plans, classroom observations, and action research projects. Findings show that the CAMCC functioned well in predicting how these teachers made decisions that impacted how they processed the reform message. When the reform message was communicated in such a way as to initiate stress appraisal, conceptual change occurred, producing changes in classroom practice. If the reform message did not initiate stress appraisal, teachers rejected the professional development message and developed heuristic responses. In order to further research and improve practice, propositions for assessments related to the CAMCC are provided.

Keywords Conceptual change · Professional development

In the current climate of high stakes accountability in the United States, professional development programs are required to demonstrate how they can effect positive

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changes in teacher knowledge, skills, and beliefs. Funding agents typically require the use of empirically supported models for professional development projects. Practices must be targeted, focused, and attentive to the intended audience. Project evaluations emphasize summative judgments about the influence of the project on participants (and quite often their students) over formative elements intended for the project designers. These requirements emphasize the need for a more detailed understanding of science teacher development and the long-term interrelationship between knowledge, skills, and beliefs. The purpose of this study was to evaluate the professional development progress of three teachers as a process of conceptual change using a contemporary model that recognizes both cognitive and affective components.

Current learning theory describes a dual processing model of information processing with a rational cognitive system working in concert with affective factors to bring about semantic restructuring of cognitive resources (Bransford et al. 1999). A robust theory of learning would account for a multitude of cognitive and affective factors while demonstrating utility through application to both formal and informal environments. Though a number of models have been proposed (Alexander 2003; Dole and Sinatra 1998), most are lacking validation in multiple contexts and few have focused on learning within the context of professional development. However, Gregoire (2003) has proposed a Cognitive-Affective Model of Conceptual Change (CAMCC) to describe professional development as a conceptual change event in the context of mathematics. If the CAMCC can be demonstrated as robust across contexts and measurable in straightforward and functional ways, it could be applied continuously to the outcomes of any professional development experience to assess a participant's status. This study sought to advance theory by testing the assumptions of the CAMCC for describing teacher development in the context of science by evaluating the model's predictive powers for a group participating in long-term professional development. Outcomes of this work included demonstrating the utility of the CAMCC in a science context as well as propositions for practical assessments in order to further research and improve practice.

Review of Related Literature

The *National Education Science Standards* (NSES) provide four professional development standards that describe how schools and school districts might envision and enact programs of science professional development that include developing teachers' professional knowledge and skills (National Research Council 1996). Enacting the NSES vision of professional development is hindered by teacher knowledge and experience with inquiry, as well as their science content knowledge. The science education reform movement emphasizes inquiry pedagogy, yet many veteran teachers have never experienced inquiry science and are trying to implement a pedagogy that is quite foreign to them and which they may not embrace (Fetters et al. 2002; Taitelbaum et al. 2008). In addition, teacher content knowledge may be weak and they may be teaching outside their subject areas (Bencze and Hodson 1998).

Designers of teacher professional development should consider, identify, and address the effectiveness and influence of what Posner et al. (1982) termed *conceptual ecologies* and what Feldman (2000) termed *practical theories*, the collection of strategies, ideas, and practices that teachers gain over a lifetime of experiences. Teachers use practical theories in their practice, which may influence how they adjust to new methodologies and teaching reforms (Gregoire 2003; Russell and Martin 2007). Many of these practical theories become the underpinnings for teacher resistance to embracing new methodologies or alternate ideas (Loughran 2007).

The intricacies of teachers' varied backgrounds form their view of how the world should or should not be, or how it might be and has an influence on the classroom (Schutz et al. 2006). If science teachers hold a worldview of science that is not compatible with the view supported by the NSES, then meeting the professional development standards may not be possible. Further, failure to be successful in attaining their goals as science teachers can lead to a problem in self-efficacy (Bandura 1997; Jones and Carter 2007) including the development of heuristic processing (e.g., if I had smaller class sizes, I would be successful)(Gregoire 2003).

In successful professional development, designers understand that teachers bring their beliefs and motivations to any training, thus making decisions very early regarding the message of the professional development. Early examination of these emotions, beliefs, and goals can lead to a discussion of conceptual change theory and strategies that influence the conceptual change process, and can be incorporated as a professional development strategy. As such, their willingness to confront their own ideas about teaching may be very difficult.

How can the NSES assist in the development of scaffolded professional development? First, it is important that teachers experience activities that permit them to study scientific problems which are current, relevant, and can be processed in a way that enables them to use collected data to make scientific meaning of the questions. Teachers benefit from conducting research that relies on a variety of media to increase their understandings of the scientific phenomena and provides them with time to reflect on their understandings (Bencze and Hodson 1998; Cooney et al. 1998; Gregoire 2003; National Research Council 1996; Taitelbaum et al. 2008). Second, teacher attitudes and abilities towards science learning, including teaching and content knowledge are reflected in their practice (Cooney et al. 1998). Time and resources for teachers to identify students' previous knowledge and to customize their instruction to address these preconceptions can be addressed during professional development (Andre and Windschitl 2003; Crawford 2000; Strike and Posner 1992). Third, it is important that teachers stress the value of lifelong learning (National Research Council 1996). Having the opportunity to collaborate, reflect and receive meaningful feedback from their colleagues (Cooney et al. 1998; Gregoire 2003), and learning to use research-based instruments for reflection, enables teachers to confront deeply held personal beliefs about their practice (National Research Council 1996). Finally, professional development programs should be coherent and based on well-conceived sets of goals aligned with the NSES.

Conceptual Change Theories and Professional Development

Given the NSES rationale for professional standards and the role of teacher goals, emotions, and beliefs, research on conceptual change can aid the design and implementation of enduring professional development. This section discusses several theories as they developed over the past 30 years and their possible contributions to the understanding of how teachers accept, reject, or integrate new ideas into their own understanding and pedagogy.

When Posner et al. (1982) first proposed their conceptual change model, they were trying to answer the question: “How do learners make a transition from one conception, C_1 to a successor conception, C_2” (Strike and Posner 1992, p. 148). They envisioned that learners confronted with a new conception must meet four vital criteria before they accept the new concept. They include “(a) dissatisfaction with the current conception, (b) intelligibility of the new conception, (c) plausibility of the new conception, and (d) fruitfulness of the new conception” (Posner et al. 1982, p. 214). Accordingly, they further described learning as taking place in a conceptual context, which they refer to as a learner’s conceptual ecology.

Ten years later, Strike and Posner (1992) revised their theory, suggesting that teachers who work to assist students in making connections between their new conceptions and their conceptual ecology might be better served by addressing conceptual change. Teachers should model rational inquiry and demonstrate themselves to be practitioners of inquiry. Teachers should investigate student conceptions before instruction, examine student conceptual ecologies, and emphasize a rational view of the world. This position correlates with the first and second NSES professional development standards and research by Schutz et al. (2006).

Duit and Treagust (2003) view conceptual change and learning as being multi-dimensional and should include epistemological, ontological, or social/affective positions. They remind us that Posner et al. (1982) first suggested that it is the learner and not the instructor who makes decisions about conceptual status and conceptual changes. Pintrich et al. (1993) argued that “students’ self-efficacy and control beliefs, classroom social context, ‘individual’s goals, intentions, purposes, expectation, and needs’ are as important as cognitive strategies in conceptual learning” (p. 178). These same affective constructs are equally important when considering professional development, because participating teachers make decisions about the professional development message in the same manner.

Gregoire (2003) was confounded by the resistance to reform that she encountered with mathematics teachers. She proposed a dual-process system and developed the CAMCC to explain the variables and events related to the processing of a professional development message (Fig. 1). Applying and evaluating a cognitive-affective approach allows for a reexamination of professional development as well as the tenants of conceptual change theory (Bencze and Hodson 1998). Gregoire (2003) asserts that “understanding how teachers’ beliefs relate to their practice and to student outcomes may be the missing link between calls for reform and teachers’ implementation of that reform” (p. 149).

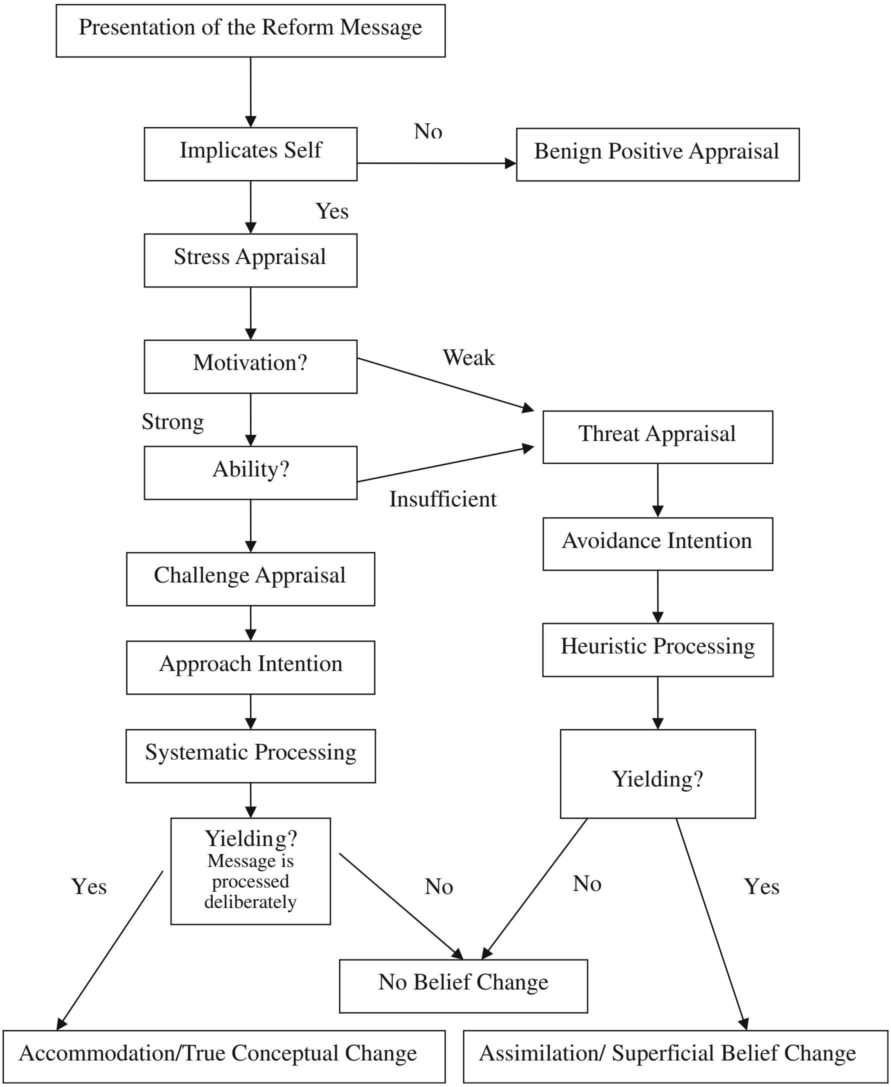

Fig. 1 Cognitive-affective model of conceptual change (Gregoire 2003)

The process of change is described with the CAMCC by following the flow of variables rationally from top to bottom. First, the presentation and processing of a reform message initiates the conceptual change process. How the reform message is conveyed at the onset of the professional development can determine whether a participant will *implicate self* and continue to be involved in the program or reject the message and engage in *benign positive appraisal* (i.e., “I already know this and it is not about me, but I’ll come along for the ride”). In essence, the participant must find the message compelling enough to stress their conceptual understanding. When teachers *appraise the threat to self*, the result may be strong enough to cause them to have the *motivation* to confront their own beliefs and understanding; otherwise they will reject the message. The same is true if participants feel that they do not have the ability or feel their abilities are not strong enough to incorporate the reform message.

The participant's threat appraisal can lead to *avoidance* behaviors (failure to participate in activities) or *heuristic processing* (making statements such as "that activity is great for your students, but my students won't be able to do it successfully"). The participant who finds the reform message a challenge but continues to systematically engage in the professional development activities can ultimately accommodate the message and change their conceptions. If the participant fails to systematically and deliberately process the message, they can still superficially process or reject it. With the CAMCC as a design and assessment framework, the critical junctures of the model could be queued and followed with individualized participant feedback and strategies. Consistent with the initial proposal of Posner et al. (1982), the CAMCC clearly delineates that for any of the reforms suggested by NSES to be successful, teacher education and professional development needs to confront teacher attitudes towards the reform message prior to the development experiences (Gregoire 2003).

Inherent in the CAMCC is the notion that professional development programs occur over time, taking advantage of teacher enactive mastery and providing time and opportunity for practice of the reform message. A second implication is the acknowledgement that teachers have beliefs about their abilities and skills (implication of "self") and that those beliefs may be at risk (Gill et al. 2004; Gregoire 2003; Sinatra and Pintrich 2003). This is a compelling aspect of the conceptual change process without which teachers may not have the motivation to engage in the internal dialog needed for processing the reform message. A third implication is that policy makers, including funding agencies, provide opportunity for reflection on the implementation of the reform message.

The purpose of this study was to use the CAMCC to evaluate the professional development of three secondary science teachers. The research participants were members of a long-term professional development project where inquiry science teaching served as the reform message. The study was guided by the following research questions:

1. In the context of science teacher professional development, does the CAMCC meaningfully describe the process of implementing an inquiry-teaching practice for three unique teachers?
2. In the context of professional development for three unique science teachers, what does the CAMCC identify as strengths and weakness of the reform message and the professional development program for fostering conceptual change?
3. What implications can be drawn from this collection of cases for developing assessments, grounded in the CAMCC, for monitoring science teacher professional development as a conceptual change process?

Research Design

A large school district in the southwestern United States served as the setting for this research project. As of 2006, the school district served a K-12 student population numbering more than 300,000 and covered nearly 8,000 square miles of geographic area. The district includes rural, suburban, and urban schools. In 2007, the number of enrolled Hispanic students reached majority status at 40%. Prior to the time of this study, the district did not generally provide long-term professional development for science teachers. Further, the short-term professional development that was provided was not planned using national guidelines.

This study was conducted within a new long-term professional development venture, born of collaboration between the school district, a state-funded regional professional development organization, and multiple partners at the local university. A three-year program for secondary science teachers was proposed and funded through a state Title II Mathematics and Science Partnership (MSP) grant. The project was initiated with the goals of improved quality of instruction focused on implementing a newly adopted ninth grade inquiry curriculum, and improved student achievement on the statewide high school proficiency exam for science. Emanating from an established need, the project incorporated science content, distance education, teacher-led professional learning communities, and ongoing professional development. Because of similarities between demographics of the school districts and the predominately urban nature of the setting, the project was heavily influenced by emerging results from a project in Detroit, Michigan (Marx et al. 2004; Rivet and Krajcik 2004).

The professional development model for the project consisted of two primary annual components, a summer institute followed by academic year coursework. The summer institute focused on developing science content knowledge, while the academic year coursework emphasized educating participating teachers on the guiding principles of the project and developing site-based action research projects. Conceptual change, self-regulated learning, and accommodation for special student populations were the three main theoretical principles underlying the professional development and became an annual emphasis for each year of the project (Crippen et al. in press). Participant knowledge and understanding of the theoretical principles was addressed by their successful completion of a series of three, two-credit hour graduate courses delivered during each fall semester.

Methodology

The methodology for this study took the form of an ex-post facto, multiple case study design (Creswell 1997). Our primary interest involved using the (CAMCC) to understand how teacher-participants processed the professional development message of scientific inquiry as suggested by the NSES. The message was defined as the intended goals, objectives and broad themes of the professional development.

The criteria used for selection of the participants was dependent on several factors, including (a) three continuous years of participation in the program, (b) three separate classroom observations, (c) a complete set of participant responses (i.e., reflective essays), (d) completion of action research projects, (e) variability of teaching assignments, and (f) magnet versus traditional comprehensive high school setting. Three secondary science teachers from the larger pool of project participants met the selection criteria, yet offered unique individual characteristics. Based on the above descriptors, these sets of data became the three cases of this multiple case study. Pseudonyms are used to protect the identities of the case participants.

Data Sources and Analysis

Data sources where identified from work products from the activities and artifacts produced for the formal project evaluation. During the first summer institute, participants were introduced to the characteristics of inquiry as defined by NSES. Using the instrument and technique described by Kang et al. (2008), participants decided whether several teaching scenarios represented inquiry. Participants, working in groups, completed and discussed their beliefs and these discussions were tape recorded and transcribed verbatim.

Participants submitted lesson plans for an ideal inquiry lesson on three different occasions, at the first summer institute, 6 months later and again in the third summer institute. Lesson planning was not addressed as an explicit part of the professional development and the submitted form of this data was not described or required. As such, we interpreted this data as a representation each participant's ideal view of enacted inquiry. Reflective essays were written throughout the three-year project and for the purpose of this study, only essay responses concerning inquiry, conceptual change theories and inquiry, and self-regulated learning and inquiry were selected for review.

Each participant's classroom was observed once during the fall and spring semesters of the academic year. Teachers selected when they were observed and were aware of the protocol. As each classroom was observed, the Classroom Observation Protocol (COP) was completed (Lawrenz et al. 2002). Two trained observers conducted observations independently and met regularly to discuss any issue until a consensus was reached. Immediately following each observation, the results were sent to the participants for review and reflection. Any inaccuracies noted by the teacher were discussed among the observers and resolved.

Using a constant comparative method (Lincoln and Guba 1985), these data were coded according to the NSES five essential features of inquiry (National Research Council 2000, p. 29). These include (a) students are engaged in scientifically oriented questions; (b) students give priority to evidence in responding to questions; (c) student explanations are formulated from evidence; (d) student explanations connect to scientific knowledge; and (e) student explanations are communicated and justified. The inclusion of 0–1 features was coded to indicate that a participant had *emergent* understandings about inquiry, 2–3 features were coded as *approaches* understandings and 4–5 features were coded as *meets* understandings. Triangulation was achieved by constant comparison of the findings among the data sources. Validity of our claims regarding the fit of the model to the case results was also addressed with constant comparison.

Case Studies

The case study results for Jan, Victoria, and Terry are described where each case outlines the participant's progression over time through the professional development project. The findings for each case are presented as initial views of inquiry, lesson plans, and classroom observations. Finally, the development of each teacher is viewed through the CAMCC.

Case Study 1: Jan

Jan is a biology teacher at an inner-city high school. She worked in a laboratory before entering teaching. Her school was built in the early 1990's, has been designated as an at-risk school, and serves a mixed population of mostly Hispanic and African American students. The school received special funding from the U.S. government for a magnet program in broadcasting. She is very confident in her science background, her abilities as a science teacher, and describes herself as a competent inquiry teacher.

Initial Views of Inquiry

When Jan's group responded to the scenario questions provided at the opening of the summer institute, their overall focus was on the presence or absence of a scientific question. Through their discussion, they added the idea that inquiry involves application of knowledge and is open-ended. Although their conversation was honest and may be reflective of inquiry along a continuum (Yager 2009), beyond the idea of a question being present, they did not discuss the other four NSES features of inquiry. Jan's group response was coded as having one NSES feature and was classified as *emergent* inquiry.

After the summer institute, Jan's responses to the essay questions indicated that she had expanded her understanding and her responses were coded as *approaches* inquiry. Jan focused on the role of the teacher in her early responses but towards the end of year one, she changed her understanding of inquiry and started to focus more on the role of the student. She stated, "I would have [students] reconcile how their conceptions prior to the lab may have influenced their experimental set up. Did [the students] design an experiment to validate their conceptions or to attempt to invalidate their conceptions?" Jan used three NSES features in her discussions.

Inquiry Lessons

Jan's first inquiry lesson plan did not have any NSES features and was classified as emergent inquiry. Jan focused on her role as an instructor and directed her students rather than acting as a facilitator as she stated in her essays. At mid-term of the first year, Jan submitted a second lesson that was found to have 2–3 NSES features and was coded as approaches/meets inquiry. In year three, she submitted the same activity that she submitted at mid-term of year two. There were no new changes to the lesson and the coding remained the same.

Classroom Observations

During Jan's initial classroom observation, the observer noted that the class was highly engaged in a discussion with Jan regarding a forensic science video on a true criminal investigation. The lesson, however, did not engage students in any NSES features and although remarked by the observer as a highly engaging lesson, was not indicative of inquiry pedagogy. The second observation occurred 7 months later during one of Jan's Biology classes where students were studying plant tissues. The observer recorded that students completed a bell assignment, reviewed the homework from the previous evening and then began a microscope lab on plant tissues. The observer classified the activity as a verification laboratory. During the last observation, the observer noted that the class was studying cell division. The class began with a review of the previous night's homework including a short discussion about the formula for photosynthesis. Students were given a test that took about 20 min. After the test, Jan lectured for the remainder of the period ending with an explanation of a worksheet to be finished for homework. The lessons were coded as *emergent* inquiry.

Jan's Development Through the Lens of the CAMCC

Participants knew when classroom observations would occur and scheduled them at their convenience. They also knew that they were being observed for evidence of inquiry pedagogy. Jan did not invite the observer to view any of her classes that utilized inquiry and did not appear to be incorporating any of the professional development. In her essays, she made it clear that she used inquiry often, yet the three observations did not occur during any inquiry lessons. Jan does not appear to have incorporated the professional development into her teaching practice.

The CAMCC indicates that Jan was engaged in *benign-threat appraisal* and rejected the professional development message, believing instead that she already was an inquiry teacher. After midterm of year one, Jan accepted some of the message of the professional development but rejected other aspects. She reacted heuristically by stating that she already was a practitioner of inquiry and did not fully accept the *challenge appraisal* and *implication of self* in the reform message, thus avoiding systemic processing. As evidenced by her writing at the time: "So I did make a few minor changes to what I've been doing, but after the summer institute, I've realized that I've been doing these things all along. Now I need to polish them a bit."

Jan did not appear to have systematically or critically reflected on her practice. At the onset of each activity, she should have been challenged to critically address her pedagogical strategies. Jan might have benefited by having her colleagues in the program provide support for her teaching practice while at the same time challenging her to process the professional development message for plausibility and fruitfulness.

Case 2: Victoria

Victoria is a biology teacher at an at-risk, inner-city high school. Victoria has a degree in psychology, has experience teaching in at-risk schools in other states, and comments often that she knows intimately the difficulties that her students face in school. Victoria's school is one of the original schools in the county and was recently torn down and rebuilt. Her classroom went from being old and ill maintained to being brand new with ample space for classroom and laboratory. Victoria, her students, and colleagues were all excited to be working in a new facility.

Initial Views of Inquiry

When Victoria's group answered the inquiry scenario questions during year one, the group suggested that inquiry involved students generating their own questions and developing hypotheses about their questions. There was some understanding that students can study questions that are given to them, but somehow inquiry involved an added motivational component. The group decided that inquiry involved more than just developing a question that students had to be in the role of teaching themselves. Although this group had great conversations about science education, their discussion only included one NSES feature and was classified as *emergent* inquiry.

Victoria's essay responses during year one revealed that she had a different understanding of inquiry than many of her colleagues that aligned more closely with the NSES. She stated, "Students need to be engaged, question, evaluate, and analyze the evidence as well as present it effectively." Her status was classified as *meets* inquiry. Victoria's essay responses included a notation that she was revamping her curriculum and taking a new approach with her students, commenting: "I met with such resistance in environmental science from the students that it was like hitting a wall." She also challenged her own understanding with the reflection: "In the past month, I keep running into comments from other teachers in workshops that lead me to believe that many, many of them really don't truly understand what inquiry is and how to implement it OR I'm way off." Finally, Victoria commented with some frustration that her students had many external influences, issues, and concerns that they brought to the classroom that affected how able they were to engage in any kind of learning activity. Victoria bluntly stated: "Try getting a student to concentrate on their lesson when they know that Dad's going to have his gun pointed at them when they get home, or that their sister is going to be thrown out of their house if their parents find out she's pregnant, or any other of a number of extreme situations I've witnessed."

Inquiry Lessons

The theme of Victoria's first sample lesson was the concept of mutation, which she developed into a simple but effective inquiry activity asking the question: "What would cause such a change in an organism?" As the lesson progressed, a scaffolding strategy was used to increase the complexity of the inquiry, requiring students to make claims based on evidence they would gather during their investigation. Student explanations for random mutations would be based on evidence determined through the investigation and the explanations connected to scientific knowledge. The activity was classified as *meets* inquiry.

Her second submitted lesson engaged students in a scientifically oriented question regarding toxic chemicals in the environment. Students were required to give priority to evidence in responding to questions and in formulating scientific explanations; but, unlike the first lesson, there was no evidence of students presenting their scientific understandings to the class. The lesson was classified as an *approaches* inquiry.

The final lesson submitted, challenged students to study population variation using pinto beans. As the lesson develops, it emerges as an effective analogue for population variation, but not as an inquiry (none of the NSES features). The lesson was classified as *emergent* inquiry.

Classroom Observations

Victoria's observation data do not support her writing. Her lesson plans incorporated features of inquiry but in application, they were absent. During two observations, students were uncomfortable with the observer in the room and refused to participate in the classroom activities. On the third observation, the school was on special schedule and classroom behavior was an issue that Victoria could not overcome.

Victoria's writing indicated that she used and understood the inquiry process better than most of her peers, including the conceptual change components, but struggled with their implementation into meaningful lessons. She acknowledged that students did not engage when the observer was in the room and was puzzled by their response. The passivity of students towards the teacher when the observer was present was unexplainable.

Victoria's Development Through the Lens of the CAMCC

Victoria's essay responses indicated that she had accommodated the professional development message, but her observation data indicates that she was struggling to operationalize it in a challenging classroom context. Victoria worked to incorporate the characteristics of inquiry into her lesson design and was successful in one, partially successful in her second, and unsuccessful in her third lesson. This finding may indicate just how difficult it is to accomplish inquiry lessons that incorporate all five NSES features on a routine basis.

From the perspective of the CAMCC, Victoria's essay responses and lesson plans provide ample evidence that she engaged with the reform message. Throughout the 3 years, she effectively used the language of scientific inquiry and wove it into her instruction. By all accounts, Victoria was systematically processing the message, and the CAMCC predicted that she would undergo conceptual change. On a personal level, Victoria frequently communicated with the other participants and with the leadership team. She discussed her uncertainty about her ability to implement the professional development. The CAMCC indicates that she was undergoing stress appraisal and was subconsciously challenging herself and developing strategies.

Victoria differs from Jan in that she believes she needs to examine her pedagogy and is willing to acknowledge that the professional development message is important to her practice. There may also be some significant and powerful influences, such as a systemic issue at her school that prevented the incorporation of reform strategies. Future work with Victoria would include more observations to determine the effectiveness of the reform message, practice with the pedagogy, and help in identifying the yet unknown influences that may be influencing her use of inquiry.

Case 3: Terry

Terry teaches biology and 9th-grade science at a suburban, comprehensive high school. Terry's participation in the professional development project included facilitating one of the breakout rooms as a teacher-facilitator. Terry is energetic and continuously challenges herself by confronting her practice and involves her students in their learning experiences.

Initial Views of Inquiry

During the first summer, Terry was in the unusual position of being a teacher-facilitator and as such had to consider all of the professional development activities prior to implementing them with her peers. This unusual situation forced her to consider the reform message intimately, so that she could in turn share it with her colleagues. As a teacher-facilitator, Terry did not participate in the group discussion on the inquiry scenarios. Data for her understandings of inquiry were gathered from her inquiry lessons, essays, and classroom observations.

Terry's essay responses during year one demonstrated that she had an understanding of inquiry that aligned more closely with the NSES definition than most of her peers. She stated that inquiry provided her with a platform for efficient teaching. She further listed the criteria of inquiry as defined by NSES and described the challenge of inquiry as "failing and not finding a better way to do it the next time."

Inquiry Lessons

Terry's first lesson plan was described as an inquiry that provided students with a scientific problem and asked them to collaboratively develop a solution. Students collected data, made decisions about whether the data was valid, and presented their findings in a portfolio. The activity had four NSES features and was classified as *meets* inquiry. Had Terry allowed the class to communicate with each other and work through their understanding, she would have met all five criteria.

Her second activity, recorded 1 year later, required students to develop the concepts of diffusion and osmosis, while her instruction blended conceptual change theory, inquiry processes, analogies, and self-regulated learning. The difference between this activity and her first activity was that she had students engaged in a whole class conversation about their findings and the interpretation of their findings using accepted scientific understanding.

Classroom Observations

Terry's first observation was conducted in a ninth grade science course that included a population of 55% special needs students. The observer noted that students were "highly engaged," providing discussion that required them to connect to previous scientific knowledge as they attempted to answer the question "Where could they find carbon dioxide in their everyday experiences?" The observer noted that Terry's students made connections to other content areas, connections to previous knowledge, and made connections to their everyday lives. This lesson demonstrated four NSES features and was classified as *meets* inquiry.

In her second observation, following Terry's direction, students synthesized slime. The observer coded the activity as directed inquiry because after making the slime, students were directed to design a method to analyze its physical properties. As Terry provided questions for students to consider, they also asked questions and made attempts to find evidence to support their hypotheses. Students communicated their findings to each other individually, then to the class. This activity used four NSES features and was coded as *meets* inquiry.

During her last observation, Terry's students worked on a teacher directed question and did not pose their own questions. The lesson proved to be focused on how to develop a concept map and was coded as *emergent* inquiry.

Terry's Development Through the Lens of the CAMCC

Terry's case provides a complement of three experienced teachers who, according to the CAMCC are each at different places. As evidenced in her writing, lesson plans, and observations, Terry accommodated the reform message and systematically processed it by addressing her self-efficacy, her beliefs about teaching and learning, and her confidence in her content knowledge. After the first summer, the CAMCC predicted that she would continue to be engaged with the reform message throughout the three-year project. Terry's participation as a teacher-facilitator certainly influenced her processing of the professional development message. The CAMCC emphasizes the importance of presentation of the message and it seems from Terry's evidence that being involved as a teacher-facilitator enhanced her engagement with the professional development.

Comparing her initial responses with the CAMCC, Terry was implicating herself with the reform message and was trying to assess how she would deal with the challenge of the message. Terry's statement about "failing and not finding a better way to do it the next time" may be indicative of how she viewed the professional development message. In other words, she interacted with the reform message on a deeper level because her stress appraisal of the message was associated with her self-efficacy and her belief in her abilities to be successful.

In the fall of year one, Terry was finding the message of inquiry pedagogy plausible and fruitful, especially when combined with learning about conceptual change theory. Using the CAMCC, Terry demonstrates motivation, possesses the ability, accepts the professional development challenge, enthusiastically approaches the professional development message, and attempts to systematically process the reform message of inquiry pedagogy. From the CAMCC, Terry appears set to accommodate the conceptual change.

Discussion

The results of this study support the CAMCC for meaningfully describing the process of implementing an inquiry-teaching practice for three unique teachers in a science professional development context. Jan's self-described expert status resulted in her engaging in benign positive appraisal. She only superficially interacted with the reform message, resulting in no belief change. Victoria engaged in stress appraisal, questioning her pedagogical skills and her ability to effectively implement inquiry instruction. Terry's role as teacher-facilitator forced deep processing and ultimately, accommodation of the message.

When applied to the complex environment of science teacher professional development, our analysis indicates a weakness in the CAMCC model due to its linear form. For example, once a participant initiates benign positive appraisal, they are removed from the process and are no longer accounted for by the model. According to the CAMCC, to re-enter the model, they must again be presented with the reform message. Practically, this may happen on a more implicit basis, but the mechanism is not included in the CAMCC. Our results would suggest a more cyclic and recursive form of the CAMCC.

Determining participant status relative to the model required a significant amount of data and its analysis was labor intensive. Without the essays, lesson plans, audio transcripts of their discussion, and other data sources, it would not have been possible to know whether the teachers were processing the reform message. In this study, once the features of inquiry were identified and the CAMCC analyzed, teacher statements were easily coded. Using the framework afforded by the CAMCC, it was possible to view the progress of the case study participants through the course of 3 years. However, trained staff were required to assess a participant's status in relation to the CAMCC by identifying the elements of the model as the teachers revealed them.

In the context of this study, the CAMCC clearly reveals strengths and weakness of the reform message as well as the professional development for fostering conceptual change. The CAMCC was applied after the professional development project occurred and by using it in conjunction with the data sources, it was clear that the leadership team could have, at any time, determined where each participant was in terms of processing the professional development message. It was also clear upon analysis that rubrics could have been developed that would have allowed the professional development to adapt as needed in order to address those participants engaged in benign threat appraisal or those stressed by self-efficacy issues. Using the CAMCC as an explicit framework for professional development implies that activities are designed with built-in self-assessments, thus providing critical formative data. Participant comments and ratings could quickly define their level of engagement with the message.

Secondly, the CAMCC worked well for assisting the professional development designers in evaluating whether participants received the reform message. One critical finding in this regard involved the explicit nature of the reform message. This is akin to the telling of a story with the ending being told before the story is unfolded. For conceptual change to occur, including subsequent changes in classroom practice, participating teachers needed to know the reform message and how they were supposed to process it on the first day of the program. For this professional development project, our use of the CAMCC afforded use of the information gleaned through years one and two that strengthened the delivery of the professional development in the final year.

In our experience, teachers are typically made aware of the professional development goals and objectives. However, the conceptual change approach used in this project, addressed the affective aspects of the dual process model. By telling teachers that they needed to implicate *self* and that this process would be stressful for them changed the dynamics of the entire professional development.

Using the CAMCC on a Larger Scale

This study lends further support to the role and importance of continuous reflection throughout any professional development experience in order to achieve conceptual change (Cooney et al. 1998; Fetters et al. 2002; Russell and Martin 2007; Taitelbaum et al. 2008). The role of reflection contributes to the conceptual change process by challenging teachers to systematically process new conceptions (Russell and Martin 2007; Taitelbaum et al. 2008). The stressors of professional development, which primarily force this need for reflection, center on the teachers' role as learner (Loughran 2007).

This study suggests that providers of professional development in science can use the CAMCC meaningfully in the planning, delivery, and follow through phases, particularly for those projects that include online components. For example, online communication and pre-project work can help participants to initiate *implication of self*. Using a coding system, with categories of emergent, approaches, and meets can greatly aid formative evaluation. Further, a simple three-category coding system affords the quantification of participant progress. Facilitated online discussion can provide meaningful and constructive collaboration as colleagues work to understand and critique the professional development message. Further, this platform allows the leaders to know if the participants are struggling and are finding the message plausible.

The CAMCC diagram can be used from the beginning of any professional development as a participant handout where each step is assigned a number. Participants can be prompted to reference the diagram and to rate and reflect on their progress. This form of activity would enhance reflection, make development explicit, and potentially enhance self-regulation.

Conclusion

Results of this study suggest that for the three case-study participants, the CAMCC was effective for describing their development. This finding adds to our theoretical understanding of professional development as a conceptual change process by demonstrating the potential for using the CAMCC across contexts. Further, this study has provided important insights into ways of using the CAMCC on a larger scale to further research as well as improving science teacher professional development.

In addition to future research related to instrument and model refinement, new studies might include taking a more critical look at the role of action research as a component of professional development, particularly in relation to active processing of the professional development message. Action research requires deep reflection on the part of teachers and could prove to be an important scaffold for facilitating translation of professional development to teacher practice. Data collection in the form of explicit journal reflections on the CAMCC could provide further insight into the conceptual change process. Finally, this project focused on high school science teachers and it would be useful to explore using the CAMCC with elementary and middle school science teachers engaged in long term professional development.

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