THE INFLUENCE OF OBSERVATIONAL EXPERIENCE AND METACONCEPTUAL TEACHING ACTIVITIES ON SECONDARY SCIENCE TEACHER CANDIDATES' CONCEPTUAL UNDERSTANDINGS OF THE PRACTICES OF SCIENCE

Jillian L. Wendt
University of the District of Columbia
jillian.wendt@udc.edu

Brandy Huderson
University of the District of Columbia
brandy.huderson@udc.edu

https://doi.org/10.25891/55qn-3k55

ABSTRACT
Research supports that the use of intentional, metaconceptual teaching practices enhances teacher candidates' conceptual change, thus affecting teacher candidates' accumulation of new knowledge and understanding. With the increased focus on and need to accommodate the calls for enhanced science teacher education of the Next Generation Science Standards and the related practices of science, it is important to consider how teacher preparation programs enact conceptual change among teacher candidates that align with the current calls. This study examines intentional, metaconceptual teaching activities coupled with observational field experiences with mentor scientists to determine whether engagement in these activities affects teacher candidates' understandings of the practices of science. Results indicate that teacher candidates did enhance their understandings of the practices of science after participation in one science methods course incorporating metaconceptual teaching activities and observational field experiences. Individual and overall results are discussed along with implications for future research and practice.

KEYWORDS
conceptual change, metaconceptual teaching, practices of science, secondary science, teacher education

Theory and research support that learning results from the interaction between an individual's current understanding of concepts and new information that is introduced through experience and instruction (Posner et al., 1982). When an individual purposefully examines conceptual understandings in light of new information and new experiences, the choice is made to either adopt new understandings that are robust and rational or to reject new understandings that fail to meet these criteria. This is understood to be the process of conceptual change (Posner et al., 1982). While learning is dependent on myriad factors, conceptual change is the process that allows learning to occur and, importantly, allows for individuals to advance in their understanding of the world around them.

Recently, a renewed focus has been given to learning in the field of science education and, more specifically, the practices of science and the applicability of such practices to day-to-day life. Therefore, education reform in the area of science has highlighted the need to identify conceptual understandings that transcend mere content and, rather, embrace the process of "doing" science (NRC, 2012). The *Framework for K-12 Science Education* (NRC, 2012) was developed to highlight the desired outcomes of effective science learning and thus served as the foundation for the development of the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013). The framework moves beyond the prescription of what science content students must learn and calls for the conceptual understanding and active engagement of students in the practices of science. To achieve this, the framework is built on the foundational ability to ask fundamental science questions and conduct scientific investigations in an effort to develop students who can think, question, communicate, and act like actual scientists in practice. The framework states that students' knowledge should be guided "toward a more scientifically based and coherent view of science and engineering, as well as of the ways in which they are pursued and their results can be used" (NRC, 2012, p. 11). Emphasis is placed on understanding "the practices needed to engage in scientific inquiry" (NRC, 2012, p. 11); thus, science education should support not only the attainment of conceptual understanding of science content but also conceptual understanding of scientific practices.

What seems to have fallen by the wayside, however, is the need to first educate teachers in ways that support both the understanding of science practices and, more importantly, how to integrate such understandings into K–12 science teaching. Loughran (2014) argues that "the very language of science teacher learning purposefully links expectations that it is not just students but also teachers who are active learners of science, congruent with the ideas of constructivism" (p. 811). As many science teachers teach science in a way that mimics how they were taught—often following approaches that are no longer considered evidence-based best practices in the field—the challenge has become how to "help student teachers see beyond their own experiences of teaching and find new ways to engage…in conceptualizing practice as something more than how they themselves were taught" (Loughran, 2014, p. 812). With this need in mind, it is suggested that teachers examine their conceptual understandings of science and of science as a practice and participate in the active engagement of the practices of science. Thus, teachers can not only learn how to think, question, communicate, and act like scientists but also learn how to adapt and integrate such practices in the context of the K–12 science classroom.

A robust body of literature exists that examines conceptual understandings held by students (Burgoon et al., 2011). However, a need has been documented in the literature to study conceptual change as it relates to teaching and learning among science teacher educators as little research currently exists (Russell & Martin, 2014). While some research supports that conceptual change frameworks may assist science teachers in developing scientifically acceptable and accurate views of science concepts (Treagust & Duit, 2008), little research exists that examines conceptual understandings as they relate to science teachers' knowledge of the practices of science. This exploratory study, therefore, seeks to examine the experiences of teacher candidates enrolled in a graduate-level science methods course that was designed to enact conceptual change through participation in an observational field experience component coupled with intentional participation in metaconceptual teaching activities.

The Practices of Science

Recent educational reform in the area of science has centered on the "power of integrating understanding the ideas of science with the engagement in the practices of science" (NRC, 2012, p. x). Reform efforts support the idea that a deficit exists in students' understanding of science as a practice—that is, how to engage in inquiry and investigation as a scientist would—as a matter of the ability to engage as adults in informed decision making and socially responsible practices. In the *Framework for K–12 Science Education*, the National Research Council (NRC, 2012) explains the importance of this renewed focus:

> Science, engineering, and technology permeate nearly every facet of modern life, and they also hold the key to meeting many of humanity's most pressing current and future challenges. Yet too few U.S. workers have strong backgrounds in these fields, and many people lack even fundamental knowledge of them. This national trend has created a widespread call for a new approach to K–12 science education in the United States. (p. 1)

While the NGSS (NGSS Lead States, 2013) is not without controversy and is, in the opinion of some science educators and science education researchers in the field, in need of further revision and refinement (Cunningham & Carlsen, 2014), the three dimensions set forth in the *Framework for K–12 Science Education* (NRC, 2012) and the NGSS serve as a foundation for science curriculum development and implementation to meet the existing call for a fresh approach to educating today's youth. The three dimensions are scientific and engineering practices, crosscutting concepts, and disciplinary core ideas. This study will focus on scientific and engineering practices, defined as:

1. Asking questions (for science) and defining problems (engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information (NRC, 2012, p. 3)

Considering that active engagement in the practices of science enables learners to experience science in new ways, thus challenging learners' pre-conceived notions and assumptions, the field experience component in this study served as one method by which the practices of science were presented to produce the cognitive conflict necessary to begin the process of conceptual change (Posner et al., 1982). Likewise, metaconceptual teaching activities were utilized to encourage teacher candidates to consider how their conceptual understandings of the practices of science aligned with scientifically accepted understandings of the practices of science and, if necessary, to make the necessary conceptual changes.

Theory of Conceptual Change

It is commonly accepted that all learners hold conceptual understandings based on prior experience when entering the classroom (Treagust & Duit, 2008). Teacher candidates are no exception. Of specific importance are secondary science teacher candidates, who may hold preconceptions that do not align with scientifically acceptable understandings of science content and science practices (Fulmer, 2013; Sadler et al., 2010; Treagust & Duit, 2008). These conceptions are termed "alternative conceptions" (Posner et al., 1982) and are more formally defined as logical ideas that are different from accepted scientific knowledge (Burgoon et al., 2011), denoting that they are not inherently incorrect as they rely on an individual's past observations and experiences but are incomplete or inaccurate understandings of science. As Yürük et al. (2011) says, "changing these conceptions with scientifically accepted ones is not an easy and straightforward process…as it requires learners to recognize and evaluate their existing and new conceptions[,] associated commitments, everyday experiences, and contextual factors" (p. 459). While teachers' content knowledge is important to their ability to teach science content in ways that align with accepted scientific understandings (Burgoon et al., 2011), teachers' conceptual understandings of science as a practice are essential to the ability to teach science to secondary students in ways that align with *The Framework for K–12 Science Education* (NRC, 2012) and the NGSS (NGSS Lead States, 2013). Importantly, if the conceptual understandings held by teachers are inaccurate, teachers may inadvertently reinforce or promulgate alternative conceptions among students (Burgoon et al., 2011). Thus, considering ways in which to enact conceptual change that align with calls for action and reform in science education (NGSS Lead States, 2013; NRC, 2012) is timely.

Several models of conceptual change exist within the educational literature (Treagust & Duit, 2008). This study, however, will focus on the epistemological and intentional perspectives of conceptual change. The epistemological perspective is grounded in the theory that, when learners experience dissatisfaction with a prior conception and an acceptable replacement conception is introduced, learners may accommodate the new conception and, thus, initiate conceptual change (Posner et al., 1982; Treagust & Duit, 2008). It should be noted, however, that the new conception must first be considered plausible, intelligible, and fruitful. In this study, new conceptions were introduced through the observational field experience component as well as instructional components related to the science methods course, such as lectures, discussions, homework, and assigned readings.

The intentional perspective is grounded in the theory that learners must "be active and…have a certain intention to learn" (Treagust & Duit, 2008, p. 301). Thus, the intentional perspective supports that conceptual change is dependent on learners' metacognition as well as their motivational and affective processes. In this study, metaconceptual teaching activities served to support participants' metacognition as they related to conceptual change, and, further, engagement in the observational field experience component supported participants' active engagement in conceptual change.

Metacognition and Metaconceptual Teaching Activities

Metacognition, defined as thinking about one's own thought processes (Brown, 1987), has been identified as an important factor in the conceptual change process (Yürük et al., 2011). Metacognition allows the learner to examine their own thoughts, prior knowledge, conceptions, and misconceptions and to adjust their conceptual understandings based on new experiences and new information, thus leading to enhanced learning and meaningful understanding. Metaconceptual teaching activities, therefore, encourage learners to consider their own thought processes as well as their current conceptual understandings and, importantly, to consider alternative perspectives that may or may not be adopted. Metaconceptual teaching activities in educational research have included the use of concept maps (Kaya, 2008), discussions, self-reflections, and other activities that encourage the thoughtful consideration of one's own conceptual beliefs (Yürük et al., 2011) in an effort to provide "a rational basis for a conceptual change" (Posner et al., 1982, p. 223).

While metaconceptual teaching activities have been shown to support the learning process (Treagust & Duit, 2008), little research currently exists that examines teacher candidates' conceptual understandings of the practices of science. While some preliminary research exists that examines the conceptual change process among teachers and pre-service teachers in general (Treagust & Duit, 2008; Yürük et al., 2011; Kaya 2008) and the role of metaconceptual activities in altering alternative scientific conceptions (Pintrich et al., 1993; Vosniadou, 2003; Georghiades, 2004; Yürük, 2007; Yürük et al., 2009; Yürük et al., 2017), research is needed that examines conceptual change as it relates to understanding science as a practice. Additionally, no research currently examines the conceptual change process among teacher candidates engaged in observational field experience coupled with intentional engagement in metaconceptual teaching activities.

One preliminary study on conceptual change and metaconceptual teaching activities examined 47 pre-service teachers enrolled in a general chemistry laboratory class in Turkey (Kaya, 2008). Participants were provided instruction regarding how to construct concept maps and how to use concept maps as a tool for assessing conceptual understandings and were encouraged to use concept maps to examine their own conceptual understandings. Using qualitative interviews, the results of the study demonstrated that concept maps were a valid tool for assessing conceptual understandings and, importantly, assisted students in revising their current understandings to align with those that are scientifically accepted.

Yürük et al. (2011) examined pre-service biology teachers' conceptual change related to understanding of flowering plants after engagement in metaconceptual activities. The metaconceptual activities included poster construction, journal writing, concept mapping, and class discussion and were focused on enacting conceptual change around alternative conceptions of flowering plants. The findings indicated that the majority of pre-service teachers' alternative conceptions were replaced by scientifically accurate conceptions after engaging in the metaconceptual activities.

Yürük, Selvi, and Yakisan (2017) further examined the metaconceptual processes of pre-service biology teachers as they engaged in metaconceptual teaching activities surrounding understanding of seed plants, including alternative conceptions. The metaconceptual activities included poster construction, concept mapping, discussion, and journal writing. Journal entries of five teacher candidates were analyzed. Results indicated that metaconceptual awareness, metaconceptual monitoring, and metaconceptual evaluation processes were activated through engagement in the metaconceptual activities. Furthermore, the results supported the idea that metaconceptual processes are multifaceted and that different metaconceptual processes can be observed in different settings and contexts. Importantly, metaconceptual processes may differ depending on teacher candidate ability and the specific content being studied. The authors further clarify that some metaconceptual processes require teacher candidates to engage in more than one process at a time. That is, in order to enact conceptual change, teacher candidates must first be aware of their conceptions and ideas, compare and contrast their current ideas with their past ideas, and monitor the consistency between new ideas and existing ideas from a variety of sources.

The current study aims to add to the literature and increase understanding of practices that support conceptual change and the formation of scientifically acceptable conceptions of the practices of science among teacher candidates. Enhancing current understanding may serve to inform future curriculum design and implementation as well as the design and implementation of professional development opportunities that assist teachers in attaining accurate conceptions of the practices of science and how to apply such practices in instruction in the secondary science classroom.

Purpose

The purpose of this exploratory case study was to understand the impact that participation in an observational field experience component paired with metaconceptual teaching activities had on students' conceptual understandings of the practices of science. Conceptual change was measured by the degree to which the students demonstrated a move from a broad and general understanding of the practices of science to a complex understanding of "the practices needed to engage in scientific inquiry" (NRC, 2012, p. 11) and, importantly, to demonstrate an understanding of how to adjust and integrate such science practices for middle school science instruction.

Methodology

Research Design

The study followed a case study design as it examined "an issue explored through one or more cases within a bounded system" (Creswell, 2007, p. 73). In this study, multiple cases or participants were included. Participation in one graduate level science methods course was considered the bounded system. Since individual participants may have experienced the course differently or may have different preconceptions of science content or the practices of science, a collective case study approach was utilized to provide a more comprehensive understanding of the impact of participating in the course on students' conceptual understandings of science and science as a practice.

Participants and Setting

Archival data was collected for teacher candidates enrolled in the residential graduate level science methods course—one course in the Master of Arts in Teaching program at a public, historically black university (HBCU) in the mid-Atlantic region of the United States, geared towards preparing urban educators. A total of five teacher candidates were enrolled in the course. One teacher candidate did not complete all assignments and, thus, was removed from the data analysis. The sample included in the data analysis consisted of one man and three women (N = 4). Candidates ranged in age from 29 years old to 60 years old. 50% of participants were African American, and 50% were Caucasian. All participants were career switchers who had some level of prior teaching experience. Three participants were not currently teaching in the K–12 classroom, and one participant was currently teaching in the K–12 classroom but as a provisionally licensed teacher that had not completed a formal teacher education program.

The science methods course was held during the Fall 2015 semester for a total of 15 weeks. The course was taught by the primary researcher of the study, and data was analyzed as archival data upon the completion of the course. The course consisted of in-class lectures and discussions, homework assignments, projects, and a required observational field experience component with faculty members at the university. For the observational field experience component, students were required to observe faculty members conducting laboratory practices (bench science) for a minimum of 25 hours over the course of the semester. The faculty members who allowed students to observe their practices were completing laboratory research in the fields of biology and chemistry. In order to allow for an accurate portrayal of how scientists conduct their work, no parameters were provided to the faculty. That is, students observed the faculty members conducting their research holistically. Students observed faculty members doing a range of activities in laboratories, including conducting fractional distillation, extracting DNA from planaria, and researching the replication of cancer cells found in human breast tissue. Faculty members were selected by the researchers due to their levels of scholarship in their respective fields, timing of current research activities (i.e., experiments) with the science methods course, and willingness to allow students to observe.

The course itself was designed to identify and affect change on students' conceptual understandings of the practices of science. Thus, metaconceptual teaching activities were provided as interventions as part of the normal curriculum of the course in addition to the required observational field experience component. Metaconceptual teaching activities included concept mapping, research experience analyses, in-class group discussions, reflections, and a group presentation, aligning with the research literature.

Procedures and Data Collection

Students participated in the normal curriculum of the course, with the major components of the course being the required observational field experience component and inclusion of purposeful, metaconceptual teaching activities. The rationale for including these components in the initial design of the course was to provide students with an opportunity to actively engage in the practices of science in order to enact conceptual change and to provide sufficient opportunities for reflection and application of conceptual understandings related to the practices of science. The class met once per week for one hour to participate in lecture and discussions, and students were required to complete weekly readings, assignments, and in-class discussions to provide sufficient instructional opportunities and assessments to demonstrate an understanding of science as a practice.

More specifically, the *Framework for K–12 Science Teaching* was introduced, including the practices of science, the NGSS, and the three-dimensional structure of the NGSS (e.g., cross-cutting concepts [CCs], disciplinary core ideas [DCIs], and science and engineering practices [SEPs]). Lectures, discussions, and activities were provided to unpack the CCs, DCIs, and SEPs, such as the activities made available online from the California Academy of Sciences (2020). Instructional activities were aligned with what each of the practices of sciences looks like, both in the field and from an educator's perspective of modeling and communicating such practices to middle school students. For instance, students read and deconstructed research articles to identify examples of each of the practices of science. Students were then asked to translate the articles in ways that would be developmentally appropriate for and understood by middle school students, while retaining the components modeling the practices of science. Debriefings on the observational field experiences occurred on a regular basis. Students also constructed and critically analyzed lesson plans to ensure accurate identification and application of the practices of science in the context of the middle school classroom. Students engaged in writing activities to reflect on how the observational field experiences and in-class instruction were informing and shaping their perspectives and understanding of effective teaching practices.

Note that the observational field experience hours were completed throughout the course, with the requirement that a minimum of 25 hours would be completed prior to the end of the 15th week. Completion of the observational field experience hours was verified by a log signed by both the student and the faculty member observed as well as follow-up email verification with each of the respective faculty members.

Following Creswell's (2007) and Saldaña's (2016) recommendations, multiple artifacts were collected and analyzed using Dedoose. A total of six artifacts were collected and analyzed for each participant: pre- and post-instructional concept maps, pre- and post-nature of science and inquiry reflections, and pre- and post-instructional research analysis reports.

Pre- and Post-Instructional Concept Maps

For the Instructional Concept Maps, students were asked to construct a concept map (e.g., Venn diagram, logic model) that articulated the characteristics of science research, the characteristics of effective science teaching, and how the two disciplines are similar and different, with a specific focus on the practices of science. Students were asked to consider what a researcher/scientist does in daily practice and how a science teacher would communicate and model those practices. Students were asked to consider the following types of questions: What are the various activities in which each engage? Within each map, how are these various activities related to each other? Is there overlap between the map for teaching and the map for research?

Pre- and Post-Nature of Science and Inquiry Reflections

For the Nature of Science and Inquiry Reflections, students were asked to write a two- to four-page reflection of their personal view, supported by research, of the nature of science and scientific inquiry and how students learn science, with a specific focus on the practices of science.

Pre- and Post-Instructional Research Analysis Reports

For the Instructional Research Analyses Reports, students were asked to write a two- to four-page analysis of their observational field experience, describing specific examples of where they identified the practices of science. Students were asked to make connections between faculty members' research activities and elements of teaching and learning in order to facilitate the effective implementation of NGSS-aligned science instruction.

Analysis

As conceptual understandings of science as a practice was the core aspect under consideration in this study, an embedded analysis of each artifact was conducted (Creswell, 2007). Specifically, following the design of Yürük et al.'s (2011) metaconceptual study, artifacts were coded in terms of the presence of meaningful application of the NRC's (NRC, 2012) Practices for K–12 Science Classrooms. Meaningful application was defined as a purposeful mention of a specific practice or an easily identifiable example of a specific practice. For instance, use of the term "inquiry" or "questioning" was counted as the presence of application of the practice "Asking questions (for science) and defining questioning problems (engineering)" (NRC, 2012, p. 3). Use of the term "argue," "discuss," or "debate" was counted as the presence of the application of the practice, "Engaging in argument from evidence" (NRC, 2012, p.3). Redundant occurrences were not coded. For ease of coding, descriptors were created for each of the Practices for K–12 Science Classrooms, as shown in Table 1.

Table 1
Descriptors Used in Data Analysis for Each of the Practices for K-12 Science Teaching

Practice	Descriptor used in Coding
Asking questions (science) and defining problems (engineering)	Questioning
Developing and using models	Modeling
Planning and carrying out investigations	Investigating
Analyzing and interpreting data	Analyzing
Using mathematics and computational thinking	Thinking
constructing explanations (science) and designing solutions (engineering)	Constructing
Engaging in argument from evidence	Arguing
Obtaining, evaluating, and communicating information	Informing

A second round of coding was conducted to identify the magnitude of accuracy for each occurrence of the NRC's (NRC, 2012) practices. A code of 1 was applied for an inaccurate conception of the practice, a code of 2 was applied for a somewhat accurate conception of the practice, and a code of 3 was applied for an accurate conception of the practice. An example of a passage coded as 1 (inaccurate) was: "A scientific model is a testable idea created by the human mind that tells a story about what happens in nature. An example of this observed during the observation was the utilization of the incubator to store the cells." This passage was coded as a 1, as the use of a scientific tool—in this case, an incubator—is not an accurate example of the use of a model.

An example of a passage coded as 2 (somewhat accurate) was: "Because of the massive volume of researchers, it is almost impossible to find a completely novel idea, however, every researcher has to come up with a different way of thinking and looking at topics in order to find an innovative way of looking at a similar issue." This passage was coded as somewhat accurate as the student indicated some understanding of questioning, but did not display an entirely accurate view of questioning (i.e., perceiving that a vast number of researchers stifles the ability to construct novel ideas or to pose new questions).

An example of a passage coded as 3 (accurate) was: "After staining and photographing them [planarian], Dr. [Sanvi] analyzes photographs for ocelli (eye) regeneration, growth and location, and lastly use[s] analysis of variance (ANOVA) statistical tests to analyze variance or differences in group means i.e. ensures that her measurements are statistically significant." This passage was coded as accurate given that the student correctly identified the process of analyzing.

An accuracy score was computed by averaging the codes applied. Thus, a higher score indicates higher accuracy. A table was created for each practice to document the magnitude of accuracy of the NRC's (2012) practices from pre-instruction to post-instruction. Throughout each step of the process, inter-rater reliability was ensured by each researcher independently coding each item, then comparison of coding to ensure alignment, and discussion, agreement, and resolution of any differing codes. Frequencies were calculated by tallying the number of times a descriptor was noted divided by the total of all occurrences.

Results

When analyzed as a group, the results demonstrated that the frequency of questioning, investigating, arguing, and informing increased, and the frequency of modeling, analyzing, thinking, and constructing decreased over time, as shown in Table 2. When analyzed as a group, the results demonstrated that the accuracy of all practices (questioning, modeling, investigating, analyzing, thinking, constructing, arguing, and informing) increased over time, as shown in Table 3. When considering accuracy of the practices, no particular misconceptions or alternative conceptions were noted as common across the teacher candidates.

Table 2
Collective Results of Frequency Analysis of Artifacts

Practice	Pre-Artifact Frequency	Post-Artifact Frequency
Questioning	44.1%	55.9%
Modeling	55.6%	44.4%
Investigating	42.6%	57.4%
Analyzing	54.5%	45.5%
Thinking	53.3%	46.7%
Constructing	52.0%	48.0%
Arguing	45.5%	54.5%
Informing	49.3%	50.7%

Table 3
Collective Results of Accuracy Analysis of Artifacts

Practice	Pre-Artifact Frequency*	Post-Artifact Frequency
Questioning	2.5	2.6
Modeling	2.7	2.8
Investigating	2.5	2.8
Analyzing	2.1	2.8
Thinking	2.0	2.3
Constructing	2.7	2.8
Arguing	2.5	2.9
Informing	2.5	2.6

*A code of 1 was applied for an inaccurate conception of the practice, a code of 2 was applied for a somewhat accurate conception of the practice, and a code of 3 was applied for an accurate conception of the practice.

Discussion

While the frequency of direct indication of modeling, analyzing, thinking, and constructing decreased over time, overall, teacher candidates were able to more accurately identify all components of the practice of science as outlined by the NRC after participation in the course. These findings are important as they indicate that the combination of metaconceptual teaching activities and observational field experiences may have contributed to enhanced understanding of the practices of science. While other factors may have also influenced students' understandings of the practices of science, the findings are promising as they provide preliminary indication that purposeful incorporation of metaconceptual teaching activities and observational field experiences are beneficial in one science teacher preparation program. These findings are supported by previous research that demonstrated that metaconceptual teaching activities enable conceptual change from alternative science conceptions to more accurate science conceptions (Kaya, 2008; Yürük et al., 2011; Yürük et al., 2017).

It is important to note, however, that the field of science that each respective teacher candidate chose to observe was not included in the archival data that was analyzed and could have played a role in the results. Previous research has indicated that content and context may yield activation of different metaconceptual processes (Yürük et al., 2017) and, thus, may impact conceptual change. Some aspects of the NGSS may be stressed more in some science disciplines than others, which also indicates that some practices of science may be stressed more in some science disciplines than others. However, the findings support that interventions specifically focused on modeling, analyzing, thinking, and constructing as practices may need to be implemented in order to enact conceptual change that supports accurate understanding across all practices of science among the sample population studied.

The findings of the current study are further supported by previously published research that has shown the positive effects of conceptual change using metaconceptual activities (Yürük et al., 2011; Yürük et al., 2017). The current study additionally builds on the existing body of research by adding observational field experiences to the existing framework, which has not been done in previous research to date. While further study and replication is needed, these findings indicate that adding the components of metaconceptual activities and observational field experiences may enhance understanding of the practices of science among science teacher educators.

The findings have implications for how we prepare science teachers and what resources are provided to teachers as they seek out training and experiences to remain current in the field. Following current initiatives within science research fields to include a "learning science by doing science" approach (Labouta et al., 2018), it may be advisable to include observational field experience components with scientists in teacher training as well as professional development regimes to allow teachers opportunities to re-engage with the practices of science.

Teacher educators and teacher education programs are, therefore, encouraged to consider the implementation of observational field experiences in science teacher preparation courses and programs in order to provide teacher candidates the opportunity to see the practices of science in action. That is, observational field experiences may allow teacher candidates the opportunity to learn how science practices are conducted in the field, enhancing their understanding of how scientists do science and thus enhancing their understanding of how to practically integrate the practices of science in the K–12 science classroom. Furthermore, it is suggested that intentional metaconceptual activities be integrated in science teacher preparation courses and programs in order to enact conceptual change and to allow teacher candidates the opportunity to engage in metaconceptual processes that enhance the frequency of accurate conceptions of science while simultaneously dispelling alternative science conceptions.

Limitations

Although the results of this preliminary study show that overall intentional metaconceptual activities combined with observational field experiences has a positive effect on conceptual change, the authors are cognizant of several limitations presented by the current research design. The sample size used in this study was limited to four teacher candidates. While appropriate for a case study design, the use of a larger sample size in tandem with quantitative measures could yield a more robust understanding of the impact on teacher candidates' conceptual change.

Research design and analysis was limited by use of archival documents. Repeating this study and engaging in interviews and focus groups with teacher candidates would enhance the data collected and allow for a more substantive evaluation of the teacher candidates' understanding of the practice of science. As it stands, the authors were not able to interact with the teacher candidates to gather interview and focus group data for this study as the study utilized archival data. Thus, some points of understanding may not have been accurately or adequately accounted for in the data analysis. Incorporation of face-to-face interviews and/or focus groups would allow researchers to better incorporate new information from teacher candidates that allows for a better analysis of conceptual change as well as the effectiveness of the approach used in this study design. Future explorations into this topic could utilize a more diverse method of data collection employing meta-analysis, incorporating various data collection methods, most notably interviews (structured and unstructured), focus groups, and questionnaires.

Teacher candidates engaged in observational field experiences in only two fields of science: biology and chemistry. Further exploration is needed to determine if similar results are found when engaging in other fields of science. Additionally, all teacher candidates that participated in the current study had some experience teaching in the middle school classroom. Results of the current study may not be generalizable to teacher candidates with no prior experience in teaching, suggesting the need for further research. Teacher candidates that participated in the current study were also enrolled in a teacher preparation program that focuses on preparing teachers for urban classrooms. Thus, the generalizability to teacher preparation programs that seek to prepare teachers for non-urban classrooms may be limited. The limitations of generalizability, however, are inherent in the case study design.

Another important limitation that should be noted is that teacher candidates' application of the practices of science in their own teaching practices was not examined in this study. Future study should examine not only teacher candidates' understanding of the practices of science but their ability to apply and integrate such understandings in the K–12 classroom.

Conclusion

From the first step of inquiry to the final step of defending the importance of scientific findings and communicating that importance to the scientific world, ultimately, the goal is to improve application of learned scientific concepts. However, in accomplishing this goal, it is crucial to ensure that the facilitators of this transition from concept to action, classroom teachers, understand the actual process of science in a meaningful way. To date, there is a dearth of published data examining conceptual understandings as they relate to science teachers' understandings of the practices of science, although research has supported the use of metaconceptual activities in enacting conceptual change of teacher candidates within specific science content. The results of the current study demonstrate that the combination of metaconceptual activities and observation of faculty members conducting laboratory practices had a positive impact on teacher candidates' understandings of the practice of science.

Acknowledgment

This material is based upon work supported by the National Science Foundation under Grant No. 1540799. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

Brown, A. (1987). Metacognition, executive control, self-regulation, and other more mysterious mechanisms. In F.E. Weinert & R.H. Kluwe (Eds.), *Metacognition, motivation, and understanding* (pp. 65 – 116). Hillsdale, NJ: Erlbaum.

Burgoon, J.N., Heddle, M.L., & Duran, E. (2011). Re-examining the similarities between teacher and student conceptions about physical science. *Journal of Science Teacher Education, 22*, 101 – 114.

California Academy of Sciences. (2020). NGSS demystified. Retrieved from https://www.calacademy.org/educators/ngss-demystified

Creswell, J.W. (2007). *Qualitative inquiry & research design: Choosing among five approaches.* Thousand Oaks, CA: Sage Publications.

Cunningham, C.M., & Carlsen, W.S. (2014). Teaching engineering practices. *Journal of Science Teacher Education, 25*(2), 197 – 210.

Fulmer, G.W. (2013). Constraints on conceptual change: How elementary teachers' attitudes and understanding of conceptual change relate to changes in students' conceptions. *Journal of Science Teacher Education, 24*, 1219 – 1236.

Georghiades, P. (2004). Making pupils' conceptions of electricity more durable by means of situated metacognition. *International Journal of Science Education, 26*(1), 85 – 100.

Kaya, O.N. (2008). A student-centred approach: Assessing the changes in prospective science teachers' conceptual understanding by concept mapping in a general chemistry laboratory. *Research in Science Education, 38*, 91 – 110.

Labouta, H.I., Kenny, N.A., Li, R., Anikovsky, M., Reid, L., & Cramb, D.T. (2018). Learning science by doing science: An authentic science process-learning model in postsecondary education. *International Journal of Science Education*, *40*(12), 1476 – 1492. https://doi.org/10.1080/09500693.2018.1484966

Loughran, J.J. (2014). Developing understandings of practice: Science teacher learning. In N.G. Lederman & S.K. Abell (Eds.) *Handbook of research on science education* (pp. 811 – 829). New York: Routledge.

National Research Council. (2012). *A framework for K-12 science education*. Washington, D.C.: National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. Washington, D.C.: National Academies Press.

Pintrich, P.R., Marx, R.W., & Boyle, R.A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167 – 199.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211 – 227.

Russell, T., & Martin, A.K. (2014). Learning to teach science. In N.G. Lederman & S.K. Abell (Eds.) *Handbook of research on science education* (pp. 871 – 888). New York: Routledge.

Sadler, P.M., Coyle, H., Miller, J.L., Cook-Smith, N., Dussault, M., & Gould, R.R. (2010). The astronomy and space science concept inventory: Development and validation of assessment instruments aligned with the K-12 national science standards. *Astronomy Education Review, 8*. Retrieved from https://www.cfa.harvard.edu/smgphp/mosart/images/sadler_article.pdf

Saldaña, J. (2016). *The coding manual for qualitative researchers*. Los Angeles: Sage.

Treagust, D.F., & Duit, R. (2008). Conceptual change: A discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education, 3*, 297 – 328.

Vosniadou, S. (2003). Exploring the relationship between conceptual change and intentional learning. In G.M. Sinatra & P.R. Pintrich (Eds.), *Intentional conceptual change* (pp. 377 – 406). Mahwah, NJ: Erlbaum.

Yürük, N. (2007). A case study of a student's metaconceptual processes and the changes in her alternative conceptions of force and motion. *Eurasia Journal of Mathematics, Science and Technology Education, 3*(4), 305 – 327.

Yürük, N., Beeth, M.E., & Andersen, C. (2009). Analyzing the effect of metaconceptual teaching practices on students' understanding of force and motion concepts. *Research in Science Education, 39*(4), 449 – 475.

Yürük, N., Selvi, M, & Yakişan, M. (2011). The effect of metaconceptual teaching activities on pre-service biology teachers' conceptual understanding about seed plants. *Educational Sciences: Theory and Practice, 11*(1), 459 – 464.

Yürük, N., Selvi, M, & Yakişan, M. (2017). Investigation of the nature of metaconceptual processes of pre-service biology teachers. *Eurasian Journal of Educational Research, 68*(1), 121 – 150.