How do prospective elementary science teachers think? This case study reveals thinking patterns common to preservice elementary teachers; identifies their behavioral characteristics while learning to teach science which are not commonly noted in current literature; provides change strategies to accelerate preservice elementary teachers embracing the holistic, constructivist, inquiry/practice-based paradigm consistent with the standards set by the curriculum.

The chapters in this book immerse the reader in a sequence of episodes in this science methods course, and reveal the adventure of turning theory into practice while analyzing student-student/student-instructor interactions and their outcomes in an inquiry-driven, flipped classroom.

Strategies presented empower preservice elementary teachers to implement national and state standards; change science learning/teaching from “business as usual” to applying science and engineering practices in the classroom; make cognitive and behavioral changes required to shift paradigms and eliminate science anxiety; pass through stages of grief inherent in the loss of dominant mechanistic paradigm.

This book will interest a wide readership including science educators; scientists and engineers; administrators, supervisors, and elementary teachers in a clinical education setting; preservice elementary teachers; and anyone seeking to improve STEM education in elementary schools.
Constructing Meaning in a Science Methods Course for Prospective Elementary Teachers
Constructing Meaning in a Science Methods Course for Prospective Elementary Teachers

A Case Study

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PREFACE

Sequenced episodes are described implementing interventions to facilitate preservice teachers of science in elementary schools shifting from a mechanistic, reductionist, didactic paradigm to a holistic, constructivist, inquiry paradigm consistent with Next Generation Science Standards (NGSS, Lead States, 2013) and Supporting the implementation of NGSS through research: Pre-service teacher education (Windschitl, Schwarz, & Passmore, 2014), a position statement of the National Association for Research in Science Teaching (NARST). Episodes illustrate responses to events (e.g., student-student/ student-instructor interactions and outcomes) interpreted through the instructor’s lens and principles of change (Loucks-Horsley, 1994). Emergent factors influencing students’ willingness to change paradigms and interpretations of students’ meaning-making processes while engaging in learning opportunities are included. These episodes, and the meanings made from them by the instructor, can help facilitate working with this audience to enhance STEM education by (a) scientists and engineers who wish to partner with this audience to share their STEM expertise and (b) teacher educators desiring to understand various ways preservice teachers of elementary science may construct idiosyncratic meanings when an instructor models the holistic paradigm engendered in NGSS. Insight into the thinking of preservice science education students can aid in designing interventions to mitigate inappropriate concept development. Further, preservice students can gain insight to validate and explain their emergent feelings when immersed in an environment that clashes with their previous formal schooling experiences.
The most precarious journey in the universe is that of an idea from my head to yours. It never arrives intact!

– Author unknown
PROLOGUE

What prompted writing this detailed account evaluating one particular elementary science methods class?

“You must have been sitting in on my class!”

I heard the equivalent of this comment many times from colleagues at professional science teacher education conferences after reporting episodes from evaluations of science methods classes for preservice elementary teachers. For over sixteen years, audiences have consistently indicated they identified with the descriptions and interpretations presented each time my research group and I shared our experiences.

My research group included a neuropsychologist, a university science educator, and doctoral candidates. Doctoral candidates were successful teachers of science in elementary schools, the more typical science education doctoral candidates with secondary school science teaching experience, and scientists embarking on second careers as educators. The elementary teachers were all second career teachers with previous science careers.

Individual conversations with highly experienced colleagues in the U.S. and other countries confirmed that the nature of my group’s experiences typified what they too experienced, as did attendance at other professors’ presentations and workshops about their science methods courses for prospective elementary teachers. For example, a preconference workshop for science teacher educators to share their experiences teaching science methods for elementary teachers was convened in 1998 at the Association for the Education of Teachers in Science, (now the Association for Science Teacher Education). The similarities in the stories shared led to a group of us agreeing to put together a monograph. The group met a few times thereafter and wrote vignettes for the book. In 2004, some of the group conducted a reader’s theater presentation at a National Association for Research in Science Teaching conference using the vignettes (Koch et al.). Life got in the way. The book project was never completed, but remained on the back burner in my mind.

Recently, the chair of a university elementary department commented that a third-year science educator, specifically hired to teach the elementary teacher audience, had shared frustrations from similar experiences in science methods classes. This early career person had been exposed to the current knowledge accumulated in the science education literature about teaching
elementary science teachers. I concluded, from the previous interactions and the findings of my research group over sixteen years, there are more identifiable characteristics common to those attracted to the elementary teaching profession as first-time college majors nationally and internationally than commonly have been reported over the past three decades (i.e., limited science content knowledge and science anxiety harbored by preservice teachers because they were traditionally not successful learners of science in their own schooling).

Further, I have worked with many scientists in various disciplines during the past twenty-five years who attempted to share their scientific research with prospective elementary teachers. Typically, they approached teaching in ways consistent with a didactic reductionist paradigm and became frustrated by the less than desired outcomes. For those few who were willing and able to devote time to learning to teach in ways consistent with a holistic inquiry paradigm, the outcomes were rewarding. An incentive for more scientists and engineers to make time to learn to shift teaching paradigms is coming from agencies funding their scientific research. The weight awarded to the plan for dissemination of findings, often referred to as the broader impact section, in a proposal requesting federal funding for science and technology research has been increased. Sharing research with people who will teach in schools has a large multiplier effect, thus a broad impact. This is, therefore, encouraging more scientists and engineers to want to learn ways to effectively educate people who will teach in K-12 schools.

All of this inspired me to write much detail about this course experience to immerse you, the reader, in a retrospective and iterative account of events in this course. I modified a traditional research organization for my story: I identified the national context of the study, a theoretical framework underpinning analysis of events, indicated methods used, gave an extensive description of the course, wove descriptions of participants’ interactions and my interpretations of them into a combined findings/discussion section, summarized highlights of events illustrating the theoretical framework, stated my conclusion, and gave recommendations for future study. I look forward to the insights you derive from my in-depth story and subsequent innovations you develop to ultimately enhance STEM learning in elementary schools.

Please enjoy my adventure.
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NATIONAL CONTEXT

My decisions for the 2014 course in this case study were influenced by the national context in the United States. The national guideline for science teaching in the United States, published in 2013, was titled, *Next Generation Science Standards* (NGSS Lead States). It requires learners to become proficient in scientific and engineering practices. The scientific and engineering practices (see Appendix A) numbers 1, 6, 7, and 8 overlap and create a synergy with *Common Core Standards* (NGA & CCSSO, 2009) in language arts (Appendix B).

In the previous national guideline from 1996 titled, *National Science Education Standards (NSES)* (NRC), these scientific practices were labeled inquiry and, or, science process skills, and were described as prominent characteristics of the nature of science. NSES did not explicitly discuss the related processes used in engineering practices. While there are multiple interpretations of inquiry, it is the signature pedagogy (Shulman, 2005) of science learning and teaching. Thus I believe becoming proficient with inquiry is necessary for those who will teach science in elementary schools.
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I documented my perception of what occurred in a flipped classroom (Knewton, 2014) when I taught preservice elementary teachers how to teach science through an experiential approach to inquiry, by modeling the holistic paradigm engendered in the Next Generation Science Standards (NGSS Lead States, 2013). My philosophy of education, beliefs about teachers’ impacts on society, and explanations of the significance I attached to each event described were integrated throughout course reflections I wrote at mid-semester (seven weeks of three hour classes per week) after systematic study of the course. I shared the reflections with students in the course as part of a change strategy explained in a later section. Students’ responses to these reflections served as member checks for this case study. My reflections shared with students are woven throughout this report.

Students had expressed serious discomfort in a previous section of this course when they could identify whose work was being discussed in class. This was true whether the work was an outstanding example, or an idea that needed to be further elaborated (Spector & Ball, 2014). I, therefore, deliberately used the vague comparative labels few, many, and most in contrast to using specific numbers to reduce students’ ability to identify exactly the individual(s) to whom I referred in the class throughout various sections of the mid-semester reflection report and continue that labeling scheme here. Few generally referred to 1–5, many to 6–15, and most to 16–30 respondents.

My rationale for emphasizing inquiry and nature of science presented in my reflections report to students was labeled, “Learning”. It follows:

The name of our profession should be learning, not teaching, and not grading. Doing systematic inquiry is doing science when investigating the natural world. Doing science is learning about (understanding-making sense of) the natural world. Therefore, learning science can be equated to learning how to learn. A teacher’s responsibility is to enable people to learn how to learn. The popular adage, “Give a person a fish he/she eats for a day. Teach the person to fish and he/she eats for a lifetime” applies here. If future teachers understand the culture and nature of science they will be able to make informed decisions about how and what to teach in STEM (science, technology, engineering, mathematics). If they do not construct appropriate meaning, they will be entirely dependent on publishers etc. for isolated pieces of information and directives. The resulting lack of coherence in their own information is apt to result in them perpetuating the myth that science is a collection
of independent facts to be memorized, with little to no usefulness in the average citizen’s life. (Spector, 2014, p. 1)

THEORETICAL FRAMEWORK

Most of today’s preservice teachers grew up in schools consistent with the mechanistic, reductionist, didactic paradigm of teaching. Thus they come to higher education to learn to teach expecting to do the same things to their future students they experienced as learners, “the way it’s always been done”. However, the desired state for learning science in schools derived from research on how people learn is quite different. The desired state is built on a holistic, constructivist, inquiry/practice-based paradigm. Thus colleges of education, including the one in which I work, serve large numbers of preservice teachers who need to engage in the same paradigm shift as inservice teachers from whom many of the researched principles of change in this theoretical framework were derived. By extension, it is appropriate to address the need for the paradigm shift in preservice teachers by transforming the principles deemed effective with inservice teachers for use with preservice teachers. The competing paradigms for teaching parallel the competing paradigms in society shown in Table 1.

Aspects of change literature relating to implementing innovations and resistance to innovation in science education in schools influenced my design of the course in this case study. Learners were required to change paradigms from viewing the world of schooling through a mechanistic, reductionist, didactic lens to a holistic, constructivist, inquiry/practice-based lens. Change literature, especially the foundational work written in the early days of efforts in the United States at dramatic large-scale reform in science education, shaped my implementation of the course and interpretation of the research on ways students responded to the course.

In the late 1950s and early 1970s, innovations abounded in science education and were usually led by scientists rather than science educators. For example, the National Science Foundation funded development of the alphabet programs: SCIS, BSCS, PSSC, ESCP, SAPA, and CHEM Study. Schools were all about change and how many innovations they could demonstrate (Loucks-Horsley, 1994). Change agents focused on professional development for existing teachers. Then the change process came under scrutiny, because innovations so often did not result in lasting improvement (NSF personal conversation, 2010).

I am a product of that era. My doctoral studies educated me to become a change agent in schools. My dissertation investigated how existing teachers
changed their classroom procedures to implement an audio-tutorial college biology course in high schools during 1975–1976. The study generated a model for the way inservice teachers could be influenced to accept an innovation (Spector, 1984, 1977).

More than a thousand miles away, foundational ideas of the Concerns Based Adoption Model (CBAM) were developing at the University of Texas Research and Development Center for Teacher Education with Gene Hall,
Shirley Hord, and Susan Loucks-Horsley as key figures of the early days (Hall, Loucks-Horsley, Rutherford, & Newlove, 1975). In the 1980s there was less interest in change and innovation, but interest was revived in the 1990s with gusto. My change agent skills led to my involvement in systemic approaches to change that became popular with local, regional, and state systemic initiatives funded by the National Science Foundation. Project 2061 introduced *Science for All Americans* (AAAS, 1989) and *NSES* was published (NRC, 1996). Preservice teacher education was part of systemic change. Although there are exemplars of preservice teacher education consistent with the vision engendered in NSES, the vision has not yet come to fruition in higher education nationwide (Yager, personal conversation, 2013; Spector & Yager, 2009).

Preservice teacher education programs were the focus of the Salish Project I and II in the mid to late 1990s, when twenty-five university research teams studied the condition of teacher preparation programs. I led the Salish I project for my university’s portion of the study. Even though the Salish focus was on preservice secondary preparation, we did discuss that similar difficulties existed for preservice elementary preparation. The research from Salish made it clear institutions educating future teachers needed to change what was done in preservice teacher education programs. Coherence and consistence within and across programs were frequently lacking (Salish I, 1997). Discussions within our Salish I team suggested lessons learned from professional development for inservice teachers were adaptable to preservice education. These lessons related to systems thinking and the rise of constructivism as a paradigm for learning. The National Science Foundation in 2000 began funding Centers for Learning and Teaching to encourage the use of the same research base in both preservice and inservice teacher education (Yager, 2014).

My research group designed and tested innovations based on lessons learned from Salish and other studies we conducted to make science teacher education coherent and consistent with NSES. Today, national interest in innovation is prominent again with questions being raised about how to make the vision in NGSS (NGSS Lead States, 2013) a reality in both inservice and preservice teacher education (Lynch & Bryan, 2014). On going issues of resistance to innovation/change continue, such as enough time, resources, and support for teachers to make the cognitive and behavioral changes required to change paradigms, regardless of whether they are first learning to teach or are veteran teachers. Resistance to change is common because
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Change … involves threats to an individual’s sense of competence (as new techniques are unfamiliar and untested); sense of control (as the outcomes and reactions of the students are uncertain); sense of confidence (as there is no base of previous experience on which to rely; and sense of comfort (as the emotions associated with three prior concepts are unsettling). (Osborne, 2011, p. 23)

Thus the principles delineated by Loucks-Horsley (1994) post CBAM, upon which to design strategies for change delineated below, remain pertinent today. Similarly, characteristics of effective instruction for inservice teachers are important for preservice teachers (Loucks-Horsley, 1994; Lynch & Bryan, 2014). My focus in this case study is on a preservice teacher audience.

CHANGE PRINCIPLES

Loucks-Horsley (1994) identified twelve characteristics of change in CBAM. The five that follow are overtly relevant to this case study:

1. “Fundamental change (learning) occurs over time, through active engagement with new ideas, understanding, and real-life experiences” (p. 2). Time enables teachers to enact iterative experiences testing new behaviors, perceive their success, and develop confidence the new behaviors will bring personal satisfaction (Spector, 1984).

2. “As individuals change their practice over time they go through predictable stages and how they feel about the change and how knowledgeable and sophisticated they are in using it” (p. 3). Preservice and inservice teachers commonly go through stages of grieving for the knowledge and comfort of the traditional didactic teaching they are losing (Spector, Burkett, & Leard, 2007). Woods (1994) labeled these stages as shock, denial, resistance and anger, struggle and exploration, depression, acceptance, return to confidence, and integration and success. Individual students move through this sequence of stages at different rates. Some skip stages. Others move easily from one stage to the next, while others experience extreme emotional responses before moving to the next stage. These variations appear to depend on the compatibility of the change with the person’s paradigm for teaching, the degree of effort a person perceives the change requires, and the support or resistance one encounters (Spector, 1984).

3. “Effective professional development programs have many attributes in common with effective teaching” (p. 4). For example, flexibility in course
design is necessary to meet the participants’ needs (Barnes & Spector, 1999). Attributes relevant to this study from Loucks-Horsley’s (1994) list of attributes for effective teaching that mirror attributes needed for teacher change to support a paradigm shift include (a) fostering collegiality and cooperation; (b) promoting experimentation and risk taking; (c) providing leadership, sustained support, appropriate rewards and incentives; and (d) assuring the change integrates both organizationally and instructionally with concurrent change efforts and individual school and district goals.

4. “There are other ways to learn other than through workshops, courses and institutes” (p. 5). Autonomous learners take advantage of community resources to continue their life long learning (Spector, 1988).

5. “Professional development can only succeed with simultaneous attention to changing the system within which educators work” (p. 6). Teachers must perceive institutional norms support change, permit failure as long as one gives his/her best effort and learns from it, and enhance aspects of teaching from which teachers derive satisfaction (Spector, 1984). Further, successful organizational change in schools and school systems emerges when a group (such as a class) functions as a learning organization (Senge, 1990).

The NARST position statement, Supporting the implementation of NGSS through research: Pre-service teacher education (Windschitl, Schwarz, & Passmore, 2014), explicated Loucks-Horsley’s third principle noted above. It identified well accepted principles for powerful teaching and suggested there is a need to use these in developing instruction for preservice teachers while implementing NGSS:

There are principles of powerful teaching for which strong consensus exists among researchers and knowledgeable practitioners. Among these are:

- organizing instruction around intellectually sensitive and complex phenomena rather than taking a “basics first” approach (see for example Lehrer & Schauble, 2005; Palinesar & Magnusson, 2001),
- eliciting students’ ideas on a regular basis to shape instruction (see for example, Hammer, Goldberg, & Fargason, 2012; Minstrell & Kraus, 2005),
- making students’ thinking visible so that their ideas/reasoning/experiences become resources for others in the class (see for example, Michaels, Sohmer, O’Connor, & Resnick, 2009; Radinsky, Oliva, & Alomar, 2010),
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- providing tools that allow students to revise their thinking over time (see for example, Passmore & Stuart, 2002; Schwarz et al., 2011),
- scaffolding talk, reading and writing – in particular students’ attempts at evidence-based explanations (see for example McNeil, 2009; Smith, Macklin, Houghton, & Hennessy, 2000),
- making explicit the “rules of the game” with regard to academic discourse and its relation to everyday language (see for example Mercer, Dawes, Wengerif, & Sams, 2004; Nasir, Rosebery, Warren, & Lee, 2006), and
- fostering meta-cognition as a habit of mind (see for example, Bransford, Brown, & Cocking, 2004; Brown & Campione, 1994).

(Windschitl, Schwarz, & Passmore, 2014, p. 3)

The preceding principles and features of change support and are supported by findings in this case study.

RESISTANCE TO CHANGE

Change literature includes studies explaining how resistance to change is exhibited. Resistance to change has been categorized in various ways by researchers. While the labels are different, their expressions in action are the same: In other words, the same scenarios describing resistance fit overall, even though labeled differently by various researchers. Zaltman and Duncan (1997) identified eighteen issues in four major categories of resistance to change, many of which are visible in this case study:

Cultural barriers to change (traditions and values conflicting with the innovation)

1. Cultural values and beliefs (“the innovation is wrong.”)
2. Cultural ethnocentrism (“my culture is superior – or the change agent thinks his is.”)
3. Saving face (I can’t do that. I’d never live it down.”)
4. Incompatibility of a cultural trait with change (“it just won’t work here because…”)

Social barriers to change (group psychology factors inhibiting implementation)

5. Group solidarity (“I can’t do this because it would be a hardship for my coworkers.”)
6. Rejection of outsiders (“nobody who isn’t ‘one of us’ could create something of value.”)
7. Conformity to norms (If I participated in this, I would be ostracized.”)
8. Conflict (“There are too many factions here pulling in different directions.”)
9. Group introspection (“I’m too much a part of this group to see its problems objectively.”)

Organizational barriers to change (client system characteristic opposing change)

10. Threat to power and influence (“If we do this, I won’t be as important anymore.”)
11. Organizational structure (“This cuts across department lines and intrudes on their turf.”)
12. Behavior of top–level administrators (“The boss isn’t doing it; why should I?”)
13. Climate for change in organization (“We don’t need to change, or we couldn’t if we tried.”)
14. Technological barriers for resistance (“I can’t understand this or apply it to my work.”)

Psychological barriers to change (individual traits and reactions discouraging adoption)

15. Perception (“My mind is made up: I just don’t see it the way you do.”)
16. Homeostasis (“All this change is just too uncomfortable.”)
17. Conformity and commitment (“This just isn’t the way people in my profession do things.”)
18. Personality factors (“I can’t do this; it just isn’t right for who I am.”)

Spector and Ball (2014) identified similar factors influencing the resistance preservice elementary teachers’ demonstrated to teaching in the holistic paradigm. The factors served as obstacles to making the paradigm shift during an emergent design qualitative study evaluating the previous implementation of this science methods course in the 2013 fall semester:

One set (… of influences) was contextual factors. The second set (… of influences) was human characteristics (factors of individuals)
CHAPTER 1

(see figure below). Contextual factors had two categories, (a) societal (the accountability era of high stakes testing and features of the millennial generation) and (b) university program features (the number of courses taken in one semester and the prominence of the mechanistic paradigm in their program of study). The human characteristics (factors of individuals) set included (a) the culture of the preservice teachers being the antithesis of the culture of science (previously identified by Spector & Strong in 2001), (b) functioning as a community of practice, (c) primary force for learning being the grade, (d) fear of loss of control in a classroom (e) lack of meaningful understanding of concepts and connections. The contextual features compounded the impact of the human characteristics (factors of individuals) reminiscent of Lewin’s formula (1936, 2008) for human behavior $B = f(P, E)$ where $B$ is behavior, $P$ is Person, and $E$ is the environment.

Another aspect of resistance to organizational change relates to the role of individuals’ defense mechanisms reported by Bovey (2001). Humans unconsciously use habitual defense strategies to protect themselves from the discomfort of anxiety caused by change. Some automatic defense
mechanisms are adaptive to change; others are maladaptive and serve as obstacles hindering change. The former include humor and anticipation. The latter include denial, projecting, acting out, isolation of affect, and dissociation. Many of the maladaptive mechanisms have been visible in my research group’s studies of the paradigm shift in science education with this preservice audience.

A variety of authors of change literature also made recommendations for strategies change agents could use to overcome resistance, such as developing a supportive environment that includes training to develop appropriate knowledge and skills, adequate time, resources, and leadership (Ellsworth, 2000). These are necessary to enable the teachers to develop perceptions that innovations are not too difficult to use in an authentic setting. Time is necessary for teachers to test innovations in a relatively safe environment. Some of these recommended strategies are evident in this case study. Thus this study supports and is supported by the literature on resistance to change.

METHOD

I engaged in participant observation in this emergent design case study (Merriam, 1997) to evaluate the course herein. I was, therefore, the research instrument for this evaluation seeking to answer the fundamental qualitative research question, “What is going on here?”

Program evaluation is the systematic collection of information about the activities, characteristics, and outcomes of programs to make judgments about the program, improve program effectiveness, and/or inform decisions about future programming. (Patton, 2002, p. 10)

Data sources included my observations in face-to-face classes; students’ weekly journals and responses to each other’s journals captured in the course’s computer learning management system (Canvas); hand written exit memos at the end of each class; my one-to-one conversations with students and the elementary department chair; email communications between the students and myself, including their responses to my mid-semester reflections; students’ self-assessment/self-evaluation responses; and products students produced throughout the course preserved in Canvas. I began by studying students’ products at mid-semester to enable me to write my reflections, as noted earlier. All the data sources were again examined after the close of the semester. Data were analyzed using a constant comparative method (Glaser & Strauss, 1967). Emergent categories were triangulated across sources until categories were saturated. I used an iterative process to write
this report, which included revisiting data sources multiple times, especially students’ journals and products, and revising my writing several times.

Member checking occurred in three ways: (a) I asked three students to read the manuscript and they confirmed the accuracy of my interpretations. (b) Each student in class was asked to take stock of all he/she had learned in the course to date in their week thirteen journal. I asked them to review the description of the course purpose and list of objectives read in the syllabus at the beginning of the course, and write the way they were achieving (or not) these items. Aspects from different people’s analysis of their accomplishments and pitfalls they overcame confirmed my interpretations in this document. (c) At the end of the semester, I asked all students to write a note of advice to future students in this course that could help them minimize their struggles to shift paradigms. Contents of these notes also confirmed my findings I reported in this document, especially those related to grades. Quotations embedded throughout this study were drawn from different students’ writings at various times throughout the semester, unless otherwise noted. They include any grammatical or spelling errors written by the students. All the names used are pseudonyms.