A NARRATIVE INQUIRY INTO TEACHING PHYSICS AS INQUIRY:

AN EXAMINATION OF IN-SERVICE EXEMPLARS

A Doctoral Thesis Presented to the
Faculty of the College of Education
University of Houston

In Partial Fulfillment
of the Requirements for the Degree

Doctor of Education
in Professional Leadership

by

Paige K. Evans

May, 2011

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ACKNOWLEDGEMENTS

Many individuals have supported me on this educational journey. I wish to thank my participants who immensely contributed to this research. For the past 2 years, we have been learning and growing professionally alongside one another. Each of these dedicated individuals spent years diligently helping their students become successful in science.

I extend my deepest appreciation to Dr. Cheryl J. Craig, my committee chair, for guiding me through the research process and introducing me to narrative inquiry. I greatly appreciate her patience, caring, and encouragement all throughout this journey. I also thank her for her careful readings, insightful comments, and inspirational ideas.

I express my sincere gratitude to my committee members, Dr. Steven Busch, Dr. Allen R. Warner, and Dr. Nora Hutto, for their guidance and the unique contributions they made to my journey of learning.

In addition, I would like to thank my colleague, Perri Segura, who supported me throughout my professional endeavors and co-taught the physics inquiry course and subsequent professional development sessions. I would also like to express thanks to my colleagues, Tonya Jeffery and Leah Shields, who were very supportive and always on hand to give words of advice and encouragement throughout my journey.

Finally, I am grateful for my family's unwavering love, support, and encouragement during this endeavor. My parents, Beverly Arbie and Howard Garrity, shaped my life from the day I was born in that they instilled in me a belief in myself that I can achieve anything I set my mind to accomplish. My sister, Jennifer Liberta, constantly inspires me to achieve my life's aspirations. My sisters, Stacy Garrity and Maureen Howard, and my step-children, Jordan, Amanda, and Beau Evans, encouraged me throughout this process. Most importantly, I am grateful to my husband and friend, Mark Evans, for his love, patience, constant encouragement, and support which have enabled me to pursue my dreams.

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Evans, Paige K. "A Narrative Inquiry into Teaching Physics as Inquiry: An Examination of In-Service Exemplars." Unpublished Doctor of Education Doctoral Thesis, University of Houston, May, 2011.

ABSTRACT

Studies show that teachers who have experienced inquiry are more likely to practice the inquiry method in their own classrooms (McDermott, 2007; Olson, 1995; Pereira, 2005; Windschitl, 2002). This study explores changes in science teachers' personal practical knowledge (Clandinin, 1986) after participating in a graduate level physics inquiry course and subsequent professional development throughout the school year. In addition, teacher participants were studied to determine the roadblocks they encountered when altering curriculum mandates in ways that would enable them to work with the inquiry method. The results of this course and subsequent professional development sessions were analyzed for the benefits of using the inquiry method to teacher learning and to ascertain whether the teacher participants would be more apt to employ the inquiry method in their own classrooms. Moreover, the results of this study were analyzed to inform my personal practice as a leader preparing undergraduate science teachers in the *teach*HOUSTON program as well as in my continuing work with in-service teachers. An inquiry course may be added to the *teach*HOUSTON course sequence, based on the discoveries unearthed by this thesis study.

This research study is conducted as a narrative inquiry (Clandinin & Connelly, 1992, 2000; Craig, 2011; Polkinghorne, 1995) where story works as both a research method and a form of representation (Connelly & Clandinin, 1990). Narrative inquiry is strongly influenced by John Dewey (1938) who believed that one must rely on past experiences and knowledge to solve current and future problems and that life experience is in fact education. This study inquires into the narratives of two teachers who are teaching secondary science in public schools. These stories illuminate the teachers' lived experiences as they co-constructed curriculum with their students. The images of teacher as a curriculum maker vs. teacher as a curriculum implementer (Craig & Ross, 2008; Craig, 2010) demonstrate what needs to be taken into account when teachers live physics curriculum alongside their students in physics classroom settings. The exemplars featured in this thesis illuminate teachers' developing knowledge as they expand their understandings of inquiry in a physics inquiry course undertaken for professional development purposes and their subsequent enactment of science curriculum in their own classrooms with their students as they, too, inquire into physics.

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PERSONAL BACKGROUND

Education is the tool that enables students to get a step ahead in life. However, will students be able to get a step ahead if they start out a step behind? When discussing the purposes of schools, Ravitch (2010) asserts the following: “They are a primary mechanism through which a democratic society gives its citizens the opportunity to attain literacy and social mobility” (p.6). Nevertheless, as Darling-Hammond (2010) maintains, “Today, in the United States of America, only 1 in 10 low-income kindergartners becomes a college graduate” (p. 3). In fact, students in public schools receive vastly different educations. This disparity has not changed much since I attended high school. I have experienced this inequity first hand. This, in turn, has shaped my goals as a teacher. Many low socioeconomic schools in the United States receive a much different education than those in more affluent areas. According to Campbell and Silver (1999), students in poor communities experience less choice of classes offered in comparison to schools existing in affluent neighborhoods. A study comparing schools (Lynch, 2000) confirms that inner-city schools of low socioeconomic status do not have the basic science equipment and instructional materials that affluent suburban schools possess. Moreover, the study reveals that lower socioeconomic schools have less qualified science teachers and a high teacher turnover rate. Darling-Hammond (2010) highlights this grave difference in opportunity in the following:

> Enormous energy is devoted in the United States to discussion of the achievement gap. Much less attention, however, is paid to the opportunity gap – the

> accumulated differences in access to key educational resources – expert teachers, personalized attention, high-quality curriculum opportunities, good educational materials, and plentiful information resources – that support learning at home and at school. (p. 28)

I grew up in a low-income, rural farming community in Northeastern Pennsylvania. My grandfather emigrated from Ireland and worked in the coal mines in Pennsylvania. He dreamed that his hard work would provide a better life for his family and those whom he touched. He passed on a desire to serve others, care for others, respect our environment, and pursue activities in life that will make the world a better place. My parents passed on the same work ethic and values to my three sisters and me. Although my parents had to work to support our family and did not have the option of a college education, they imparted my grandfather's final dream of having his granddaughters graduate from college. My family and I assumed I was prepared for higher education because I was in the top 5 percent of my high school class and had mastered all levels of math and science offered at my high school. Once my college courses started, I realized that I did not possess skills equal to most other students who had attended suburban high schools in affluent areas.

My poor preparation became painfully apparent during my calculus class at Penn State my freshman year. I took calculus as my first math class in college along with several other freshmen. I utilized the study skills that I had learned throughout my academic career which consisted of studying the samples and doing the assigned homework. I worked and re-worked problems from the book and thought I was prepared for the first exam. When I received my grade back from my first exam, I received a "D."

I was humiliated as I had never received any grade that low in my entire life. Looking back on this experience, I realized that not only was I inadequately prepared academically, I also did not understand the basics of the system. One of the main problems was that my instructor was difficult to understand since his first language was not English. Being one of the first in my family to attend college, I did not realize that you could simply change instructors if you were not compatible with the instructor to whom you were assigned. In subsequent years, I learned to seek guidance from those farther along in my major to determine which professors were more skilled at teaching. Additionally, I learned to switch instructors after the first or second class if I determined that their teaching style was incompatible with my learning style.

My roommate in my freshman year was, by way of contrast, from a wealthy suburban area outside of Pittsburgh. I realized this when I went home with her one weekend to get a break from school life. The houses were much nicer and larger than any I had ever seen. Additionally, she educated me on the different subdivisions and told me who of her friends lived in each subdivision. Living in one of the nicer subdivisions was important to her. This was the first time that I had heard of the term subdivision since my home town was very small. She had at least five different bathing suits and a huge walk-in closet full of clothes besides the clothes she had in her college dorm. Her dorm was freshly decorated around a theme and everything matched, while my dorm room consisted of used sheets, pillows and blankets that we found at my house. She had over 100 classmates attend Penn State. On the other hand, I was the only person attending Penn State main campus from my entire school's graduating class. She was in my calculus class freshman year and never studied for class since she had taken this class in high school. She stated that she was just taking this class to help pad her GPA as she fully intended on receiving an A for this class. Sure enough, she received an A on her first exam and subsequent exams. From where she was positioned, she did not understand how I could get such low grades when I studied as much as I did which further added to my embarrassment and frustration. Through hard work and determination, I was able to overcome the shortcomings of my high school education; regrettably, many of my friends dropped out of college and moved back to my home town.

Looking back, I now realize that I was educated in a system with less resources and lower expectations than those of most of my peers from higher socioeconomic communities. Although I did not realize this during my own schooling, this inequity is built into our society and results in unequal educational outcomes between children from wealthy communities and children from poor communities. As maintained by Darling-Hammond (2010), “the wealthiest school districts in the United States spend nearly 10 times more than the poorest, and spending ratios of 3 to 1 are common within the states” (p. 12). My own schooling consisted of a basic curriculum with three tracks: college prep, business, and regular. I took the college prep track and took the most advanced courses that my school offered while my freshman roommate was able to complete several Advanced Placement (AP) courses in high school and even enrolled in college courses as a high school student. Although I was educated in a system set up for mediocrity (i.e., Kozol, 2005; Nachtigal & Haas, 1988; Pollard & O’Hare, 1990), some of my teachers were excellent and had high expectations for my future. I believe these teachers, along with family support I had, are the reason I was able to overcome many obstacles and succeed despite the school I attended.

I do not have many memories of high school courses since these came easy to me. I rarely had to study and was able to finish most of my homework in study hall, lunch, or another class when we were not doing anything. I do remember being excited about athletics; I participated in three sports yearly: cross-country, swimming, and track. I actually started my high school cross-country team. My school only had a boy's cross country team and my track coach from 8^{th} grade got me interested in starting a girl's cross country team. I was the first person on my team and went on to recruit eight other members that were friends, or members of other sports teams that were not in season. Additionally, my coach would tell me the workouts and I would be in charge of making sure that we finished the workouts daily. I found out that I was good at motivating athletes and had a great time serving as a pseudo-coach for the team.

My lackluster experience as a student along with my love of coaching is why I chose teaching as a profession. I chose to become a science teacher because it was academically challenging and would afford me a better opportunity to obtain a job. My priority as an educator is to have high expectations and provide a top-quality education for all students regardless of their race, gender, or socioeconomic class while being aware of the unique individual learning needs of each student. This includes providing resources that would be otherwise unavailable to many students.

PROFESSIONAL EXPERIENCE

After graduating from Penn State, I decided to travel overseas and work in Japan and Korea for two years to pay off some bills and experience a different culture. After my experience in Asia, I began what I consider to be my first public school position. I was finally going to work in a public school! My goal was work in a high poverty school and that is exactly what I did. In Soledad, CA, I worked in a high poverty school of over 96 percent Hispanic population. My first assignment was to teach 7th grade math, 7th grade science, 8th grade science, and one sheltered science class. This class consisted of students who were not quite proficient enough at English to be in a regular science classroom. I had an aide to help the students when they had difficulties with the language. The classrooms were traditional with rows of desks and an overhead projector. The science stock room consisted of items that were old broken and some of the chemicals were most likely carcinogenic. We did not have any great science equipment; however, I did the best that I could do with limited equipment. If the overhead projector was not working on a particular day, I would not be able to have the students write down any information for fear of having to turn my back on the students which could result in a gang uprising. I learned this the hard way early into this particular teaching experience. I had turned my back on the majority of students to help a small group in the back of the room. Subsequently, a fight broke out and many other students joined in the fight. I was appalled and ushered all of the other students outside and called the principal to break up the fight. One major ruled at that school was to never break up a fight for fear of triggering a lawsuit. While breaking up a fight, an instructor could inadvertently hit another student and injure him or her thus being subjected to a lawsuit.

I became involved in extra-curricular activities such as the science fair, track and field, and the junior honor society. This afforded me the opportunity to get to know my students on a more informal basis. Although the students were just 40 minutes from the coast, most had never seen the ocean. This became evident on one of our class trips for the Junior Honor Society. I was able to obtain free tickets to the aquarium and one of the school board members lent me her suburban van to take a small group on this excursion. I vividly remember the looks on the faces of my students when we rounded the bend and the view of the bay appeared. They reminded me of little kids with their sheer excitement. Later on that year, I was able to take a small group of Honor Society students skiing at Lake Tahoe. I had a friend that lived in Sacramento that agreed to let the whole group camp out in their house and we raised money through car washes and bake sales to cover the cost of the ski rentals and lift tickets. When we started up the hill and they saw just an inch of snow on the ground, they wanted to get out of the van immediately. I waited until there were several feet of snow before I stopped to let them play in the snow. We had snowball fights and made snow angels and snowmen. This is one of my best memories of teaching at this particular school. While they were in the school building itself, they maintained a cool and reserved demeanor and were careful not to act too excited or show too much emotion. To see a small group of students feel comfortable enough to be so excited was more rewarding than any other experience that I had in the classroom.

One recollection that is still vivid to this day is when I went off campus to complete my parent-teacher conferences. The goal of everyone in our school was to conference with 100 percent of the parents. Since many parents worked in the migrant fields during parent conference time, this sometimes meant that we would have to travel to students' houses to meet their parents. In order to meet the expectation of 100 percent meant that I would need to make a home visit to the migrant worker camp. It was a housing facility made up of several small houses on a compound. I was escorted by a male teacher since I was told that it would be dangerous to make this trek myself. We drove up the dirt road that led into the compound and found the address. I knocked on the door with trepidation. What I saw on the inside of the house will stay with me forever. A woman answered the door. I told her who I was and explained why I was at her house. I was met with graciousness. Approximately 10 kids filed out of the 2 room house so that we could have our parent conference. The floor to the building was slanted and there were flies swirling about – sometimes landing on the mom's arm which she did not swat away. There was an old table with 2 metal chairs. I was offered one of the chairs and the mom took the other chair. I was offered something to drink. When they opened up the refrigerator, it was empty except for 1 can of Orange Crush which was offered to me. I accepted the soda since I did not want to offend anyone; however, I felt badly about taking the last thing that was in the refrigerator. We completed our parent conference and left the compound. Although we knew that our students came to us with various backgrounds, seeing this first- hand made it more real. I truly could not believe that we had students in the United States living in such poverty; I naively believed that poverty at this level only existed in third-world countries. I truly understood that our students were coming to us hungry and without any academic resources which made it difficult for our students to study in and outside of school. This fueled my determination even more to make a difference in the lives of my students. I decided that I would take the advice of the 8^{th} grade science teacher and attend the Monterey Bay Institute Mathematics Project. This was designed for teachers to learn how to teach mathematic concepts with manipulatives which promoted a deeper conceptual understanding by the students. I felt that I was meeting the objectives with the science students but failing miserably with the math students since my background was primarily science. With high expectations and teamwork, the number of 7^{th} grade students that progressed into higher math levels such as algebra increased dramatically. Also, the number of students that finished 8^{th} grade and continued to high school improved. This was a shared goal of our school since many students of migrant workers did not advance beyond an eighth grade education. Working in this community was extremely rewarding because I truly made a difference for my students. I had students that had set academic goals beyond and eighth grade education because they were successful for the first time in their academic years. For the first time, many of my students experienced success in science and math. I had put on the school's first science fair and was able to finance it with a grant. We had a science club after school where the students would conduct their experiments and record the results. The students were able to put their results on a professional looking tri-board and they were excited about their final presentations. One student who was well-known for disrupting many classes participated in the science fair. He told me that he was sure to fail because the teachers did not like him. Although he came up with what I thought was a great experiment, he was correct in that he only came in fourth place. I believe that some of the teachers did grade him more harshly because they did not like him. Fourth place was still a success for him because first place through sixth place all received ribbons.

I was extremely fortunate in my undergraduate secondary science preparation as a preservice teacher in that I had several field experiences prior to my student teaching semester. For at least three semesters prior to student teaching, I was able to work with successful science teachers writing and enacting science lessons in local area schools. This allowed me to ensure that the teaching profession was a correct choice for my future and enabled me to obtain valuable experiences that helped prepare me for my student teaching semester. Most of my colleagues never taught or observed in a classroom until their last semester of college which was student teaching. Many of my colleagues would not have chosen teaching as a profession if they had been able to work in schools prior to student teaching. Furthermore, many of my colleagues had a difficult time in their student teaching semester because it was the first time they interacted with students and teachers in the school setting.

Additionally, I learned about different teaching methods such as inquiry learning and had to prepare different lessons to enact these types of learning. The biggest lesson that I gleaned in my undergraduate teacher preparation program is that it is important for students to be engaged in the learning process. Although, inquiry and discovery learning were addressed, I did not fully grasp how to enact these pedagogies in my classroom. The pervasive method of teaching utilized in most classrooms was to lecture, write notes on the board, and pass out worksheets. I tried to make my science classroom more hands-on; for this reason, I was criticized by some science teachers and other veteran teachers for the active learning that took place in my classroom. I believe that many teachers have a perception of what a successful classroom looks like. If students are experimenting and involved in hands-on lessons, the classroom does not always appear to be orderly and therefore it could appear that I was not managing my class well. Additionally, it was taboo for students to have fun in the learning process. To some veteran teachers, learning could not occur in an environment where students were working with science equipment and conversing with other students. They attributed my different style of teaching to my youth and assumed that I would come around to the traditional way of teaching that had worked for years. Although I did have to lecture and give notes as well, I tried to make this as engaging as possible.

In my subsequent teaching positions, I strove to have an active learning environment. Furthermore, I transformed "cookbook" labs into labs where students would have to do some type of discovery. However, there were still times when the students still did not learn the intended objectives. At times, there seemed to be a disconnect between the objectives and what was learned in my classroom. In theory, the students should be learning the intended objectives; however, in practice I was not getting the results that I desired. Through experience, I later learned that each class is unique and what works for one class may not work for another.

Inquiry is not a new way to teach as it has been around for several decades (Davis, 1979; NRC, 1996, 2000; Thomas, 1968). It began with Dewey (1933, 1936, 1938, 1944) who called for active learning on the part of students and the classroom as a metaphor for the laboratory of life and continued with Schwab (1960, 1960/1978b, 1962, 1966), who drawing on Dewey, believed that students should employ the same processes that scientists engage in to discover scientific concepts. As a pedagogy, scientific inquiry is based on constructivism and finds its antecedents in the work of John Dewey among others. In 1916, John Dewey maintained that science concepts were best taught through the inquiry method. It took 40 years for this initiative to develop into a large scale curriculum development movement when the National Science Foundation sponsored several curriculum development projects such as the Biological Sciences Curriculum Study, the Physical Science Study Committee, and the Earth Science Curriculum Project to name a few (Lawson, 2002). Many teacher professional development sessions guide teachers on how to teach their students through the inquiry process. I attended several of these trainings myself and had full intentions of changing my classroom to more of an inquiry-based classroom. Once, I started the year with an inquiry lab where students had to write several questions that they could answer about a marble. They had to pick the questions that were testable and devise an experiment that they would test. For most, it was a frustrating experience since they previously had not been exposed to this type of teaching. Most students were used to being told what they had to learn and memorize. I almost had a revolt in my classroom when I started out the year with a scientific inquiry as the students were frustrated that they had to generate their own questions and perform their own experiments. It did not help that my students went to their former teachers and complained about my method of teaching. My students wanted to be told what to do; they had been conditioned, like Pavlov’s dogs, to being directed what to do. Since I was the only physics teacher at that particular school, the students were “stuck” with me and gradually learned to be more involved in the learning process. My plea to my students was to “stick it out” for at least six weeks and they would begin to feel more comfortable and become better problem solvers through this process. Throughout the first six weeks in my classroom, students would be involved in several inquiry-based lessons and gradually become more comfortable with this type of teaching. They would realize throughout the six weeks that I was not going to give them the answers to their questions and they would take more control of their learning.

PHYSICS INQUIRY COURSE

"What you have been obliged to discover for yourself leaves a path in your mind that you can use again when the need arises" (G.C. Lichtenberg).

My true understanding of teaching physics as inquiry began during the first course of my master's program in which I took a content course that was taught solely through inquiry. In my past, as far back as my undergraduate degree, I was taught that it is imperative that students are actively engaged in the learning process and that students must take part in discovering scientific concepts. Throughout my professional career as an educator, I strove to have students actively learn through laboratories and hands-on activities; however, my students were not making the connections from the hands-on activities and laboratories to developing a deep understanding of physics concepts. It was not until after I took a course whereby physics was taught through inquiry that I realized that active learning did not necessarily equate to inquiry. Just because students were involved in a hands-on physics lab, it did not mean that they were constructing their own knowledge. In fact, many of the hands-on experiences were labs where they verified concepts that they were already taught. According to Driver, Squires, Rushworth, and Wood-Robinson (1994), students need to be active and construct meaning to scientific principles. Following Dewey, they believe—and I concur—that "experience by itself is not enough, it is the sense that students make of it that matters" (p. 7).

During the Physics by Inquiry curriculum, I developed concepts based on inquiry experiments; used those concepts to develop rules and patterns; and developed equations that could be utilized to solve circuits and determine brightness in bulbs. Furthermore, I formed my own mental model for determining the brightness of bulbs in complex electric circuits. I became a product of inquiry-based learning and it was not until that semester that I truly understood the power of learning through inquiry. Additionally, we kept a journal in which we catalogued our thoughts, frustrations, and personal growth throughout the course. Looking back, journaling was a large component of the course in that I was able to articulate what it felt to learn through this manner and to finally change my own idea of what a proper classroom should look and feel like. I was able to solve circuit problems with equations to determine the brightness of bulbs; however, I could not look at a configuration to determine which bulb was brighter without relying on equations. I would write in my journal as to how I truly understood circuits for the first time in my professional career which was embarrassing since I had taught this concept to students for several years. In one of my journal excerpts, I proclaimed the following:

> I am so frustrated with coming up with the rules for circuits and will certainly empathize with my students and be cognizant of their frustration level when developing their own mental models. After teaching for several years it is good for me to feel like a student again so that I can truly understand their thoughts and frustrations. Sometimes, I feel stupid in that I have taught circuits for years but did not even know that it was the power that determines the brightness of the bulb. I wonder how many misconceptions that I have fostered in my own students over the years? (journal entry, June, 2005)

Research supports that students can obtain a deep conceptual understanding of physics by forming mental models. In the article, *Implications of Cognitive Studies for Teaching Physics*, Redish states that “the goal of physics teaching is to have students build the proper mental models for doing physics” (Redish, 1994, p. 800). Moreover, studies showed that when more time was devoted to concept attainment rather than solving problems, students had the same or higher rate of success in solving problems when compared to students in more ”traditional” physics classes (Redish & Steinberg, 1999). As the student, I was experiencing the power of the above statements; I learned that through active engagement, discussion, and facilitation by the instructor, I developed a deep understanding of physics that will always have a clear path to the forefront of my mind.

Throughout the course, the instructor emphasized the importance of the teacher as a facilitator of knowledge. This will lead to student directed learning; furthermore, skillful questioning by the teacher and in the investigation/homework is essential to concept development by the student. Studies conducted by researchers such as Arons (1999) show “The majority of students have to be guided into series of investigations by being supplied with some initial suggestions and leading questions (not cookbook instructions that destroy all inquiry)” (p. 1065). In other words, it is the student that constructs the learning; and the teacher acts as a facilitator for that to occur which mirrors Dewey’s philosophy that the student must be coached instead of being told. Nobody else can see for him, and he can’t see just by being ‘told’, although the right kind of telling may guide his seeing and thus help him to see what he needs to see” (Dewey, 1944, p. 151). It was not until becoming a product of inquiry learning myself that I truly understood the power of learning science through inquiry. Furthermore, my own content level increased significantly as I had to form my own mental models of physics concepts. By reflecting upon my own learning, I was able to improve my practice. Reflective practice is advocated by Schön (1983) who maintains that all can benefit from reflecting on their behavior.

EXPERIENCE AFTER THE PHYSICS INQUIRY COURSE

Subsequent to taking this course, I embarked upon a journey to change my own teaching strategies. I planned to change my teaching methods to parallel those I had experienced in the Physics by Inquiry course. I slowly converted my lessons to be more inquiry-based. I started with the electric circuits unit. I had several activities that were mainly verification labs. The students would learn the formula and then go through a laboratory experience to verify that the formula actually worked. I was able to utilize much of what I had learned in the Physics by Inquiry class and have the students discover the relationships between the variables. This took longer initially; however, I did not have to re-teach the information. Additionally, their test scores improved tremendously from those of previous years. Subsequent to the circuits unit, I continued to find other units and converted them from more of a hands-on, verification approach to that of an inquiry approach. This led to a deeper understanding of concepts by the students that I was able to perceive through their in-depth lab reports. I had students construct their learning though inquiry and problems relevant to their own lives. I did not start from scratch in that I utilized some of these methods in the past in a slightly different order and less effective way. Therefore, I did not have to reinvent the curriculum; just strengthen it by what I learned in the Physics by Inquiry class.

To evaluate the effectiveness of my improved curriculum, I compared unit test scores from previous years to unit test scores subsequent to employing the inquiry method. After careful analysis, it was clear that my students were more successful in their coursework. Additionally, my drop rate significantly decreased as students were more engaged in the learning process. I learned that if I approached the subject matter in a way whereby students were constructing their own knowledge, then my students were more than capable of learning difficult physics concepts at a much deeper level than they had in the past. After two years of teaching this particular unit utilizing the inquiry method, the average score on my unit test was high into the A range. At first, I was not comfortable with such a high score on the test and my instinct was to make it more difficult. After reflecting with my colleague, we decided that there is nothing wrong with all students achieving at a high level. After all, that was our goal as physics educators.

My next step as a teacher leader was to encourage other physics teachers to embrace teaching through the inquiry method. This proved to be very challenging and was met with resistance by most of the teachers on the physics team. I was finally able to convince one of my colleagues to switch the order that she taught the electrical circuits unit. I encouraged her to try and do the lab prior to the notes. She did this and was amazed at the results. She said that subsequent to the inquiry experience, the notes which typically took a whole class period to go over only took about ten minutes since the students already knew the material through experiencing the inquiry lab. My colleague wanted to try the rest of the unit and then became a believer in the inquiry process.

Having another colleague embrace this pedagogy accelerated the transformation of the curriculum. The next step was to get others to embrace teaching through the inquiry method. This is where my eyes were opened up to how difficult it is to try and change the perception of how physics can be taught. I was met with two obstacles: one was the idea of how a class could be taught; the second obstacle was the low level of content that many teachers possess. Many teachers have a routine that they feel comfortable with in the classroom. They believe that the teacher must be the disseminator of knowledge and they do this by giving notes and going over practice problems. Subsequent to the practice problems and formal lesson, students may then engage in the hands-on component which consists of a verification experiment to show what they learned was correct. The goal of some teachers is to figure out a curriculum and not deviate from it at all. In fact, some teachers give the same multiple choice Scantron exams year after year. It was very difficult to break this mold. In some instances I was able to encourage teachers to try out a new lesson. We were engaged in professional learning communities at the time and this helped my cause since we were to all bring our best lessons for others to try. This is when it became apparent that the content level of teachers was very low. Because you cannot predict what direction the students will take in an inquiry lesson, the teacher has to have a great amount of content knowledge to know whether or not the student is going down a good path or whether that student must be re-directed. Teachers that teach by inquiry must also be ready to help students with misconceptions that they may possess.

In my current position, I teach preservice secondary science teachers. The pedagogy embraced is learning through the inquiry method and utilizing the 5E lesson plan cycle. The students take four courses whereby they experience planning and teaching inquiry-based lessons prior to student teaching. I assist the students with lesson plan preparation and teaching. Our students have a major in the subject matter that they will eventually be certified in to teach and I am largely responsible for the pedagogy portion of their course work. My first group of student teachers was very excited to put into action what they learned in our program during their student teaching semester. Although I did not expect that our students would be able to teach daily through inquiry, I believed that they would at least be able to try some of the lessons they had prepared. I fully understood that their mentor teachers would most likely be traditional teachers; however, I still thought that they would be open to our students to trying new methods of teaching. The student teaching semester consisted of our students mimicking what their mentor teacher had taught which consisted largely of notes and verification labs. I was able to have a student teacher teach two inquiry lessons after meeting with the mentor teacher and student teacher on several occasions. This particular student teacher was very excited at the results and could not wait to try more of this when she had her own classroom.

Although professional learning communities can be a positive way to plan lessons, it may also become a hindrance for our new graduates obtaining their first teaching job. According to Hord (1997), professional learning communities should encourage constructivism in that the self-initiated learner works with peers to improve teaching quality. However, the most common teaching pattern emphasizes a teacher-centered approach which may be further embraced by professional learning communities. First year teachers may be encouraged by a large group of traditional teachers to utilize their lessons. Furthermore, their inquiry-based approach may not be embraced since these types of lessons require much more preparation. For this reason, I believe that a two-prong approach must be embraced. I believe that current teachers would benefit from learning content through inquiry in order to deepen their content understanding and also re-define their image of what a proper classroom should look like. Additionally, I believe that the first and second year teachers need a great amount of induction support in order to help navigate the system and employ the pedagogy learned in their teacher preparation courses.

Many teachers have pre-conceived notions regarding a proper class based on their own experience as a student. To Windschitl (2002), "If teachers are willing to "re-culture" these kinds of classrooms, their first obstacle is the influence of their own personal histories as learners. Most teachers are themselves products of traditional schooling" (p. 151). Undoing several years of learning in a lecture type format is a challenge that must be undertaken if teachers are to feel comfortable with a different type of teaching format such as inquiry learning. "Teachers are more likely to be guided not by instructional theories but by the familiar images of what is proper and possible in the classroom settings" (Elbaz, as quoted by Windschitl, 2002, p. 151). Since many teachers were products of a lecture-type learning environment, they may not be familiar with the inquiry method except for what they have read about in a book or studied briefly in college. Learning through inquiry should not be limited to student learning as teachers can also best learn through the process of inquiry. In order to dispel the lecture-type image that many teachers possess regarding proper physics teaching, teachers can learn content through the inquiry method which will serve two purposes: (a) they can have a deeper conceptual development of the concepts by their own "step-by-step" conceptual development; (b) they will experience the inquiry method first hand, thus being able to change their mental model of the proper classroom.

Eventually, I believe that some undergraduate classes should be taught through inquiry. Although this may not seem feasible, it is occurring at other universities in Texas. I plan to teach a physics inquiry course in the future. To inform this course, I will begin to teach a physics content course through inquiry this summer. The purpose of teaching this physics inquiry course is two-fold: I hope to improve my own practice through self-reflection as well as improve the content knowledge and ability to teach physics as inquiry of the participants of this professional development. As my students engage in learning science as inquiry, I will be conducting my research as inquiry.

A physics inquiry course was developed using McDermott's Physics by Inquiry Volume I (McDermott, 1996) as a resource and model for teaching teachers. Utilizing this type of teacher professional development was designed to augment the content knowledge of the teachers on a deeper level while allowing teachers to experience the process of inquiry learning. According to McDermott et al. (2000), "Whether intended or not, teaching methods are learned by example. If the ability to teach by inquiry is a goal of instruction, teachers need to work through a substantial amount of content in a way that reflects this spirit" (p. 413). Additionally, the notion of separating science instruction from instruction in pedagogy diminishes the value of both for teachers. Therefore, teachers may not be able to adapt a teaching strategy to a novel situation (p. 416). Consequently, learning science content as inquiry will benefit science teachers as this may influence their perception of what a typical classroom should look like. Moreover, teachers may feel more prepared and confident in teaching science through inquiry. It is anticipated that teachers will be more comfortable with this model of teaching and better prepared to employ this method of teaching in their own classrooms.

A graduate level physics inquiry course was taught at the University Houston in Sugar Land during the summer of 2010. Teachers that teach in high needs schools as determined by the Texas Education Agency's Academic Excellence Indicator System (AEIS) were chosen to participate in this physics inquiry course. According to Joyce and Showers (2002), student achievement through staff development can be achieved when a group of professionals learn together and apply what they are learning (p.4). Therefore, teachers completed physics modules in groups of two or three at their own pace. A typical module had teachers perform experiments, make predictions as to the outcome of the experiment, as well as answer probing questions to analyze results with a facilitator. Teacher and facilitator discussions included questions over concept development as well as how these modules might be beneficial in their own physics classrooms.

In order to determine the needs of the teachers, pre-tests were administered to establish which specific topics will be covered as well as ascertain misconceptions that the teachers possessed. Many teachers have ill-formed definitions of science concepts; thus, these teachers may be passing down their own misconceptions to their students. Ineke, Van Der Valk, Leite, and Thoren (1999) reported that a correlation exists between the conceptual difficulties teachers possess and the conceptual difficulties their students possess (p. 61). After careful analysis of the pre-tests, activities were chosen to support intended learning. Throughout the professional development, learning was assessed through discussion and completion of activities. Additionally, post-tests were administered to ascertain mastery of the objectives.

RESEARCH PUZZLES

My research puzzles have to do with the teachers' physics inquiry course, subsequent professional development sessions, and the physics modules that were created. My questions are: Will the physics inquiry course and professional development experiences impact how much physics content is learned? Will learning physics through inquiry impact the attitudes teachers have toward teaching through inquiry? What roadblocks do teachers encounter when trying to enact inquiry lessons? Can teachers better overcome these roadblocks after inquiry-based physics course and professional development experiences? The results of this physics inquiry course and subsequent professional development sessions will be analyzed to ascertain the influence of using the inquiry method for teacher learning and to determine/consider whether the teacher participants will be more apt to employ the inquiry method in their own classrooms subsequent to the previously described teacher professional development experience. The convergence of these two practically oriented themes, both of which are unraveling currently in my professional life as a science educator, form this thesis's aggregated topic.

CHAPTER TWO: LITERATURE REVIEW

INTRODUCTION

This chapter outlines my review of literature which pertains to the following main and subsidiary research questions: How does learning through inquiry impact the quality/quantity of physics that is learned? How does learning physics through inquiry impact the attitudes that teachers have toward teaching through inquiry? Are teacher participants more apt to employ inquiry learning subsequent to learning science as inquiry? What are some of the roadblocks teachers encounter in their experiences of trying to teach science as inquiry? In an attempt to study the aforementioned questions, I begin with common conceptual misconceptions that both teachers and students possess regarding heat and temperature to better facilitate deeper understanding of these physics topics. Additionally, literature that pertains to science/physics reform and professional development will be reviewed prior to embarking on this physics class and subsequent professional development sessions. The need for teaching science as inquiry as well as the historical development of inquiry will be studied in order to understand the theoretical underpinnings of inquiry. Finally, the teacher as curriculum maker vs. teacher as curriculum implementer will be studied to ascertain whether teachers create inquiry lessons for their own classes and to determine barriers to teaching science as inquiry at their schools.

OVERVIEW OF PHYSICS CONCEPTS

An understanding of the differences between heating (or more commonly "heat"), temperature, and internal energy is essential before students can fully grasp more complicated concepts such as thermodynamics which are presented in typical high school physics classrooms. Difficulties in understanding these topics will impede students' understanding of ideal gas laws and thermodynamic processes. Although heating and temperature are widespread concepts throughout both elementary and secondary science curriculums, students enter the high school and college classrooms with very little understanding of these concepts (Warren, 1972). In fact, the way these concepts are commonly referenced in science classes, as "heat" and "temperature," may be a source of misunderstanding for the students. Many authors have found that using heat as a noun may contribute to students' misconceptions. Zemansky (1970) contends that "referring to heat in a body" is one of the three common errors that writers of introductory chemistry or physics textbooks make (p. 298). Zemansky states "There is no such thing as the 'heat in a body.' Heat and work are methods of energy transfer, and when all flow is over, the words heat and work have no longer any usefulness or meaning" (p. 297). According to Sozbilir (2003), the difficulty in understanding heat and temperature may arise in part from the terminology used in every-day life and in school (p.36). Summers, as reported by Sozbilir, argued that "using 'heat' as a noun should be avoided and 'heating' should be used as a process" (p. 27). As a result, careful consideration must be given to the teaching methods and language utilized to foster conceptual development in order to address and confront students' misconceptions. Schwab would call this terms of inquiry (Craig & Ross, 2008). If we don't understand one another's terms, we cannot fully understand what the other is talking about because words, without explanation, hold different meanings for different people.

Does the inability to understand temperature and heating stem from the lack of knowledge teachers possess or the way the material is communicated to students? Physics theories can be grasped through experimentation, guided questions, and applications of concepts. Inquiry lessons coupled with constructive discussion among students in collaboration with the teacher help students cultivate connections between ideas; however, implementing inquiry-based lessons requires the teacher's in-depth knowledge of the subject area. According to McDermott (2007), "teachers need intensive preparation in both the content and the process of physics" (p. 761). In order to teach effectively, teachers must possess a strong background in science content as well as learn new methods of teaching that will cultivate conceptual development of science concepts with their students. A physics inquiry course along with professional development on the subject of heating and temperature can accomplish both; teachers will develop a deep understanding of heating and temperature as well as become participants in inquiry teaching and learning themselves. As a result, teachers may likewise employ inquiry instruction in their classrooms as a consequence of the modeling.

COMMON MISCONCEPTIONS

Difficulties in understanding heating and temperature pervade all levels of education. According to research, for many students the term 'heat' invokes a substance or property of an object and temperature is thought of simply as the quantification of heat. Note that, in much of the literature (Erickson, 1979; Pak, Cho, & Go, 2007;

Sozbilir, 2003; van Roon, van Sprand, & Verdon, 1994; Warren, 1972; Zemansky, 1970), authors refer to 'heat' without making it clear that it is a process which could potentially introduce the misconception (or reinforce the everyday conception) that heat is a substance. When possible throughout this thesis, the term 'heat' will be referred to as 'heating' (as was also done in the study described here) in an attempt to distinguish the scientific concept from the everyday conception and convey the idea that what is commonly referred to as 'heat' is, in accepted scientific terminology, actually a *process*. Erickson (1979) used a conceptual inventory with children of ages 6-13 to identify misconceptions pertaining to heating and temperature. Prevalent misconceptions included the inability to differentiate between heating and temperature; believing that 'heat' refers to a substance; and thinking that more 'heat' contained in an object will result in a higher temperature, when in fact, in physics nomenclature, an object cannot contain 'heat' (p.228). In a more recent study, Paik, Cho, and Go (2007) reported that Korean students of ages 4-11 thought that the temperature of an object is related to the size of the object. For example, a typical response to a question would be that larger ice cubes have a lower temperature than smaller ice cubes. Students also thought that metal spoons had higher temperatures than wooden spoons when both were placed in warm water and allowed to come to equilibrium (p. 298).

The inability to differentiate between heating and temperature persists in elementary school and is not addressed in introductory physics classes.

> Although the distinction between heat[ing] and temperature can be conveyed to children at elementary school level, this is rarely competently done even though excellent curricular materials exist for this purpose. It would be well if college

> and university teachers were aware that many students come to their classes using the terms synonymously as teachers have done it in school. (Aarons, 1999, p. 1065)

Students' misunderstanding of heating and temperature persists in the high school and in introductory physics classes in college since teachers presume that students have previously mastered these concepts. As maintained by Jasien, Graham, and Oberem (2002), it is assumed that students have grasped the rudimentary ideas of heating and temperature; therefore these basics are not addressed (p. 889). Other research has shown that many students at the university level cannot discriminate between heating and internal energy. Warren (1972) conducted a study of students entering universities in branches of science and engineering to assess their understanding of heat[ing] and internal energy. Students were to define heat[ing] and energy and the relationship between each. Not one gave meaningful definitions or stated the first law of thermodynamics (p. 43). Warren reported that most students had not heard of internal energy and the few that had heard of internal energy harbored misconceptions that 'heat' and internal energy were the same quantity (p. 43).

In another study, it was shown that students failed to mention a temperature change in adiabatic processes. Rozier and Viennot (1991) studied approximately 2000 students in the first four years at the University of Paris and 29 teachers at an in-service training program. The authors had students and teachers complete eleven questionnaires that probed how students and teachers understand multi-variable problems such as the ideal gas law, $PV = nRT$, where P is pressure; V is volume; n is the number of moles; R is the universal gas constant; and T is temperature. When asked why pressure increases in an adiabatic compression, 50 percent of the students that explained the pressure increase either justified their answer in terms of volume decrease and closeness of particles. Lacking in their answer was any discussion of the mean speed of particles or temperature (p. 160). It is not surprising that students cannot fully explain adiabatic compression since they have ill-formed mental models of heating and temperature. Before advanced topics of thermodynamics can be delved into, students must first grasp an understanding of the differences between heating, temperature, and internal energy.

Another typical misconception students possess is the idea that 'heat' is a state function. This may stem from the fact that students believe that heat is a substance that an object possesses instead of a transfer of energy from one body to another. Students will be unable to fully understand the first law of thermodynamics in which 'heat' and work (as defined in physics) are process quantities and internal energy is a state function if these misconceptions are not addressed prior to teaching a thermodynamics unit. Van Roon, van Sprand, and Verdonk (1994) conducted a study because of the difficulty first year university students were having when studying concepts involving thermodynamic processes involving work, heat[ing], internal energy, and enthalpy. The findings suggested that "freshman, just arrived from secondary education, use 'heat' as a 'state quantity' and not as a 'process quantity'" (p. 136). This is not surprising since 'heat' is used in every-day language as a noun and generally represented as a substance, as in "You are letting the heat out of the house." A process, of course, is also represented by a noun, but in a much more abstract sense.

SCIENCE/PHYSICS REFORM

Much research (McDermott, 1993, 1996, 2007; McDermott, & Shaffer, 1992; McDermott, Shaffer & Constantinou; 2000) has been done as to how students best learn physics concepts. Active engagement in the learning process has always been crucial to concept development. According to Dubson (2007), "Trying to learn physics by watching your instructor do physics is like trying to learn piano by watching your piano teacher play. It is remarkably ineffective" (p. 252). Students would benefit from learning heating and temperature concepts conceptually before learning these concepts quantitatively. Studies have shown that time utilized in the classroom for hands-on investigations coupled with leading questions and meaningful discussion can eliminate many misconceptions in physics (McDermott & Shaffer, 1992). Additionally, Redish and Steinberg (1999) concluded that students need to be more actively engaged in learning rather than just listening to a professor lecture and watching him/her solve difficult physics problems. This also proved to be the case when preparing science teachers. As maintained by Jasien and Oberem (2002), in-service teachers learned more when using Physics by Inquiry curriculum (McDermott, 1996) during a three-week professional development than teachers that learned through traditional lecture (p. 893). McDermott, Shaffer, and Constantinou (2000) maintain that teachers need to have a deep conceptual understanding of physics concepts. As a result, they need to be afforded the opportunity "to understand not only what we know, but on what evidence and through what lines of reasoning we have come through this knowledge" (p. 412). The Physics by Inquiry curriculum is a laboratory-based course in which teachers develop a deep understanding of physics concepts by experimenting and establishing scientific concepts based on a concrete experience. This curriculum was developed by The Physics Education Group at the University of Washington which has over 25 years of experience in preparing teachers to teach physics and physical science by inquiry. As maintained by McDermott et al. (2000),

> Science instruction for young students is known to be more effective when concrete experience established the basis for construction of scientific concepts. We and others have found that the same is true for adults, especially when they encounter a new topic or a different treatment of a familiar topic. Therefore, instruction for prospective and practicing teachers should be laboratory-based. (p. 411)

Such thinking resonates with Dewey's (1938) theory of experience and the importance of the laboratory of life and Schwab's notions of inquiry as a "generic envelope" (Schwab, 1962) both of which pattern how scientists think.

It is evident that special attention must be given when developing lessons over temperature and heating. Even though these concepts may have been taught previously, teachers cannot take for granted that their students fully understand these topics. Addressing student misconceptions is an essential component of the lesson. If misconceptions remain unaddressed, further learning stagnates. Through pre-tests and facilitating rich discussions with the students, teachers can ascertain the prior misconceptions concerning a concept that students may possess. Additionally, students' questions serve as valuable information which the teacher can scrutinize to inform instruction. Shepard et al. (1992) asserts that "Research in cognitive science has shown that formative assessment, used to discover what a student understands or does not understand, can be a powerful tool in targeting instruction so as to move learning forward" (p. 275). Bransford, Brown, and Cocking (1999) have also emphasized the need for teachers to identify and work with students' misconceptions when developing concepts. Questions asked by students can serve as valuable information which the teacher can use to guide instruction. As Driver et al. (1994) make clear, "Teachers need to be aware of pupils' existing ideas, of learning goals and also of the nature of any difference between the two, when they are planning and implementing teaching" (p.8). Moreover, "Once the teacher has identified the nature of any differences between pupils' thinking and the science viewpoint then it becomes easier to plan activities which will support intended learning" (p.10). Additionally, pre-assessment can occur throughout the lesson where students can predict possible outcomes while going through inquiry experiments. Minstrell (2001) has students write down their predictions and explanations before experimentation and continues to assess students throughout the entire lesson (p. 235).

It is imperative to utilize peer instruction to achieve goals of enhanced conceptual development (Crouch & Mazur, 2001, p. 970). The usage of science equipment can also improve learning. Research in education supports that peer instruction coupled with hands-on experiences is an integral component of concept development. Driver et al. (1994) asserts the following: "Teaching and learning based on concern for constructing ideas requires children not only to 'do' laboratory work, but also to think about how their investigations relate to the ideas they are developing" (p. 7). Furthermore, in a study that examined the effects of tool usage on student learning, Carter, Westbrook, and Thompkins (1999) made the following assertion: "Within the small–group setting, an individual's use of tools is directly related to the frequency of verbal interaction of that individual; and there is a direct correlation of verbal interaction and conceptual growth" (p.97). According to Driver et al. (1994), "pupils need to see themselves as actively engaged in constructing meaning by bringing their prior ideas to bear on new situations" (p. 7). Learning temperature and heating concepts lends itself to hands-on inquiry learning. Also, every-day objects can be used to help facilitate understanding of these concepts.

In another article regarding student interactions, Ciardiello (2003) emphasized that learning is enhanced with student discussion. Ciardiello contends that students will develop metacognitive skills through their own questioning. An emphasis on metacognition has also been shown to improve transfer of concepts (Bransford & Schwartz, 1999). If students understand how they best learn new concepts, they can use this life-long skill throughout the rest of their high school and college careers.

In order to develop and facilitate effective lessons, teachers must possess a deep conceptual understanding of the topic taught. In a study conducted by Galili and Lehavi (2006), seventy-five experienced high school physics teachers were asked to define various physics concepts in order to ascertain shortcomings in the teacher training (p. 521). Only 7 percent of the teachers associated 'heat' with a form of energy that transfers from a hot body to a cold body; most defined 'heat' as a form of energy being contained in a substance (p. 530). Furthermore, while most related temperature to measuring 'heat' or a type of energy or velocity, most did not mention the word "average" when defining temperature (p. 529). Many teachers have ill-formed definitions of temperature and heating; thus, these teachers may be passing down their own misconceptions to their students. Ineke et al. (1999) reported in a study that a correlation exists between the conceptual difficulties teachers possess and the conceptual difficulties their students possess (p. 61).

In addition to a strong background in content, teachers must also understand how students learn. Grossman, Sheonfield, and Lee (2005), for example, explain:

> Effective teachers need subject matter competence; they need to know how to solve the problems they pose to students and to know that there are multiple approaches to solving many problems. But such competence is not enough. Making the right choices as a teacher depends on knowing what kinds of errors or mistakes students are likely to make, being able to identify such mistakes when they occur, and being prepared to address the sources of the students' errors in ways that will result in student learning. (p.205)

Many teachers have pre-conceived notions regarding a proper class based on their own experience as a student. Even when preservice mathematics and science teachers are trained in best practices, many resort to teaching in ways that conflict with this training; many teachers resort to teaching the way they were taught. Moreover, Olson (1995) contends the following about teachers: "They continue to do things in ways they have found meaningful and useful in the past. They teach as they were taught" (p. 132). In Pereira's (2005) view, "All too often, my student teachers behave in ways that seem to contradict the vision they have developed, as if they had snapped back to a former state when faced with the realities of classrooms and schools" (p. 71). Pereira believes the first step in education reform is to change the way that experienced and prospective teachers learn subject matter (p. 71). His students are provided with numerous experiences in which mathematics is learned in a novel way. An integral part of the learning process is for students to confront their own emotions in learning through this new model. His students keep journals that highlight how they are learning and their reactions to their learning in order to facilitate the process of re-culturing their experiences as learners of mathematics. "All this is so different from the prior experiences of my students that it helps to reacquaint them with who they are as learners of mathematics and to give them a new vision of what they might become" (p. 71).

SCIENCE INQUIRY

Teaching science as inquiry has been recommended by a myriad of resources including the *National Science Education Standards* (National Research Council [NRC], 1996); *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993); *Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (National Academy of Sciences, 2007); and *America's Lab Report: Investigations in High School Science* (NRC, 2005). The National Science Education Standards (1996) defines inquiry as the following:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p. 23)

Although the importance of utilizing inquiry approaches when teaching science is addressed through both preservice and in-service science teacher training, research has shown that the majority of teachers fail to employ inquiry teaching methods into their teaching repertoires (Salish I Research Collaborative, 1997). Scientific inquiry is a pedagogy that is based on constructivism and finds its antecedents in the works of Dewey, Schwab, and Piaget among others.

The forerunner of constructivist education, as prefigured in this work, is John Dewey's progressivism. Dewey (1933) maintained that learning is deep-rooted in the experiences one enters into and the knowledge that arises through a process of inquiry. This process of inquiry stems from a perplexing experience or a discrepant event that leads one to think reflectively and engage in some type of action to solve the problem. Furthermore, these actions must occur in a social context with a community of learners who construct their knowledge together (Dewey, 1938). One must rely on past experiences to solve the problem. In this case, reflective thinking involves both the past and the future in that students build upon their previous experiences and knowledge to construct new knowledge.

Dewey emerged on the educational scene when there was a struggle as to who would control the American curriculum. Who determines the curriculum of the public school? The control of curriculum has changed from the teacher, to the subject matter; and from the subject matter to the child. Kliebard (2004) maintains in *The Struggle for the American Curriculum*, "With the change in the social role of the school came a change in the educational center of gravity; it shifted from the tangible presence of the teacher to the remote knowledge and values incarnate in the curriculum" (p. 1). The dichotomy in pedagogy continues to exist and has roots back to the 1800s. Is it the "child" or the "subject" that should dictate curriculum? Dewey (1902) stated the following: “One school fixes its attention upon the importance of the subject-matter of the curriculum as compared with the contents of the child’s own experience” (p. 13). Eliot and later Harris emerged as “humanists” that were more concerned with curriculum than the development of the child.

> The question of the course of study, he said, is the most important question which the educator has before him, and the curriculum, in Harris’s mind, should take its cue, not from the vagaries of the children’s interests of their spontaneous impulses, but from the great resources of civilization. (Kliebard, 2004, p. 32)

Hall emerged as the developmentalist, who proceeded basically from the assumption that the natural order of development in the child was the most significant and scientifically defensible basis for determining what should be taught (p.11).

Dewey believed that an integration of both is necessary for successful learning on the part of the child to take place. As Kliebard (2004) surmised, “Dewey’s position in curriculum matters is best seen not as directly allied to any of the competing interest groups, but as something of an integration and, especially, a transformation of the ideas they were advocating” (p.26). Dewey (1902) used the analogy of a map to explain how both schools of thought can be integrated.

> But the map, a summary, an arranged an orderly view of previous experiences, serves as a guide to future experience; it gives direction; it facilitates control; it economizes effort, preventing useless wandering, and pointing out the paths which lead most quickly and most certainly to a desired result. (p. 27)

Those that are totally child-centered run the risk of the student wandering aimlessly with very little learning. Those that are entirely curriculum-centered run the risk of the “three evils" which include a lack of connection to the child, a lack of motivation, and an inadequate development of reasoning powers (pp. 31-33). Dewey later affirmed:

> That which we call a science of study puts the net product of past experience in the form which makes it most available for the future. It represents a capitalization which may at once be turned to interest. It economizes the workings of mind in every way. (p. 27)

Dewey believed that reading, writing, and arithmetic could be most effectively taught within the context of use and especially in connection with the basic occupations around which the curriculum revolved (Kliebard, 2004, p.66). In talking about his Laboratory School, Dewey (1936) affirmed the following:

> The underlying theory of knowledge emphasized the part of problems, which originated in active situations, in the development of thought and also the necessity of testing thought by action if thought was to pass over into knowledge. The only place in which a comprehensive theory of knowledge can receive an active test is in the process of education. (p. 464)

One of Dewey's most salient contributions to science education is that he advocated an experimental approach to science teaching (Dewey, 1944). His influence is evident in the national standards and even in the Texas Essential Knowledge and Skills (TEKS) in that Dewey purported the processes of science were as important as scientific knowledge. The TEKS devote a significant portion of the objectives to the Nature of Science and process skills and the rest to content knowledge. However, do the process skills have to be separate from the content knowledge? Many science educators view these as two distinct types of objectives instead of utilizing one to achieve the other.

Dewey believed that the scientific processes could be the means to obtaining scientific content knowledge (Bybee & DeBoer, 1994, p. 371). According to Dewey (1944), "The end of science teaching is to make us aware of what constitutes the more effective use of mind, of intelligence" (p.120). Dewey advocated utilizing the scientific processes which would result in obtaining scientific knowledge.

> What is desired of the pupil is that starting from the ordinary unclassed material of experience he shall acquire command of the points of view, the ideas and method, which make it physical or chemical or whatever…the dynamic point of view [is] the really scientific one, or the understanding of process as the heart of the scientific attitude. (p.122)

Joseph Schwab (1960/1978b) advocated that students learn scientific concepts through inquiry and arguably brought teaching science as inquiry into the education domain from his background as a scientist. Schwab recommended that students should work in the laboratory prior to the teacher introducing formal scientific principals and concepts. In other words, students should learn science similar to the way that scientists conduct their research. He purported that "scientific research has its origin, not in objective facts alone, but in a conception, a construction of the mind" (Schwab, 1962, p. 12). Furthermore, he suggested three different approaches for teachers to utilize while teaching science which also represented different levels on the inquiry continuum.

> First, laboratory manuals or textbook materials could be used to pose questions and describe methods to investigate the questions, thus allowing students to discover relationship they do not already know.

> Second, instructional materials could be used to pose questions, but the methods and answers could be left open for students to determine on their own.
>
> Third, in the most open approach, students could confront phenomena without textbook- or laboratory-based questions. Students could ask questions, gather evidence, and propose scientific explanations based on their own investigations. (NRC, 2000, pp. 15-16)

Another category for teaching science is to have "invitations to inquiry" (Schwab, 1962, p. 95) in which students are presented with individual problems that intrigue them. These problems are not merely "applications of principles"; they would engage students to experiment to obtain knowledge. As per Schwab,

> First, the treatment of science as enquiry is not achieved by talk about science or scientific method apart from the content of science. On the contrary, treatment of science as enquiry consists of a treatment of scientific knowledge in terms of its origins in the united activities of the human mind and hand which produce it; it is a means for clarifying and illuminating scientific knowledge. (p. 102)

The National Research Council depicts the Essential Features of Classroom Inquiry and Their Variations in the following table.

Table 1.

Essential Features of Classroom Inquiry and Their Variations (National Research Council, 2000)

Essential Feature	Variations			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to **evidence** in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulate **explanations** from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence and how to use evidence to formulate explanation
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication
More ——— Amount of Learner Self-Direction ——— Less Less ——— Amount of Direction from Teacher or Material ——— More				

Schwab significantly advanced the notion of inquiry based instruction and contributed to the Biology Sciences Curriculum Study (BSCS) and had a direct influence on the curriculum standards for science, despite the irony that he was adverse to generalized statements of learning from which the human qualities are stripped. Fundamental to the instructional materials was the active involvement of students in the learning process and that students were “doing rather than being told or only reading about science” (NRC, 2000, p. 16). To Chiappetta and Koballa (2009) “content with process” is a way to view teaching science as inquiry and students should engage in laboratory and investigations designed to answer questions that perplex them (pp. 126-127). They maintain that science teaching at the secondary level emphasizes the products of science and often excludes the thinking utilized and the “minds-on experiences” essential for students. Consequently, the learning achieved has little meaning for students (p. 124). As Chiappetta and Koballa have explained: “Again, the goal is to learn about phenomena by bringing into instruction the ways and means that are used to arrive at various understandings” (p. 126).

Jean Piaget (1970) believed that knowledge is a result of an interaction between the learner, social interaction, and the environment. Piaget was a Swiss psychologist who was one of the first to shift the locus of learning from a behavioral aspect to a cognitive aspect (Llewellyn, 2005, p. 33). Piaget is famous for his four developmental stages which include the following: sensory motor, preoperational, concrete operational, and formal operational which are the underpinnings of the constructivist philosophy. He believed that all humans go through these four stages in mental development at varying rates (p. 34). Additionally, Piaget (1973) maintained that students must re-discover or reconstruct truths and that knowledge is simply not imparted to the child (p. 16). Moreover, he believed that this may cause some teachers to fear that they will no longer have a role in the classroom. According to Piaget, "What is desired is that the teacher cease being a lecturer, satisfied with the transmitting ready-made solutions; his role should rather be that of a mentor stimulating initiative and research" (p. 16). Piaget believed that learning has to be an active process and constructed from within (Kamii, 1973, p. 199). This is in direct opposition as to what is currently happening in the classroom. For most, teaching is seen as presenting the material to students; then, students practice this new material until they master it. Piaget also believed that social interactions are important for intellectual development and that learning must be based on experiences rather than language (p. 201). Some progress has been made in that experiences enhance the learning; however, many still regard the "correct" answer as the ultimate goal instead of the thinking involved to obtain the correct answer (p. 201). In the Piagetian school, "The task of the teacher is to figure out what the learner already knows and how he reasons in order to ask the right question at the right time so that the learner can build his own knowledge" (p. 203). Kammi (1973) elaborates on the role of a teacher in a Piagetian school in the following way:

> The role of the teacher in a Piagetian school is not one of ready-made knowledge to children. Her function is to help the child contrast his own knowledge by guiding his experiences…The role of the teacher is not to impose and to reinforce the "correct" answer but to strengthen the child's own process of reasoning. (pp. 212-213)

Piaget theorized that students form mental models which are called schemas by engaging in hands-on experiences; it is into these structures that new ideas are assimilated. It is important to note that these schemas could be a result of misconceptions that a student harbors (Llewelyn, 2005, p. 33). The pedagogical implication of the Piaget's theory suggests that learning must be truly active with social interactions among peers. The role of the teacher is to provide opportunities for children to construct their own knowledge through their own experiences, not through the logic of the adult (Kamii, 1973, p. 214).

To translate Piaget's theory into practice, a high school teacher must be aware that students entering his/her classroom could be at the concrete or formal operational stages of development. As a result, teachers can help make the transition from a concrete stage to a formal operational stage by structuring their lesson plans accordingly. According to Llewellyn (2005), science lessons should be sequenced compatible with a student's cognitive development. By utilizing a constructivist approach to lesson design, teachers should first introduce the topic with a hands-on exploration and then help the students make sense of the exploration instead of the other way around (p. 35). Llewellyn sums up Piaget's theory into four principles:

1. People develop through "stages" of cognitive growth.
2. Knowledge is a result of every-changing social interactions between the individual and the environment.
3. Knowledge is constantly being constructed and reconstructs from previous and new experiences.
4. Cognition is self-regulating within the individual and the interaction with the physical and social environment. (p. 36)

5E LESSON PLAN CYCLE

Today, the 5E lesson plan cycle which is utilized in many science classrooms is deeply rooted in the instructional methods of Dewey, Schwab, and Piaget as understood by those who borrowed from them. The five parts of the lesson plan cycle are the following: Engage, Explore, Explain, Elaborate, and Evaluate (Biological Sciences Curriculum Study [BSCS], 1997).

During the Engagement phase of the lesson cycle, the teacher elicits the interest and focus of the students through an interesting scenario or a discrepant event which, according to Dewey (1933), would lead one to think reflectively and engage in some type of action to solve the problem. Piaget maintained that people have categories of knowledge, called schemas that help students to interpret information and understand concepts (Llewellyn, 2005). When a situation arises that is inconsistent with a person's schema, the child may disregard the new information or accept a new notion based on a new experience. During this phase, students can also share their previous experiences with the topic. As stated earlier, Dewey believed that one must rely on past experiences to solve a problem. As indicated by Llewellyn,

> From a constructivist perspective, the Engagement phase also provides an opportunity for the teacher to activate learning, assess prior knowledge, and have students share their prior experiences about the topic. The teacher can note possible naïve conceptions or misconceptions stated by the students. (p.47)

During the Exploration phase, students develop questions, make predictions, and test their predictions (Llewellyn, 2005, p. 47). This closely parallels Schwab's belief in that the students obtain scientific content knowledge through experimentation and experiences. The Exploration also allows students to work together to solve a problem which is essential to both Dewey's and Piaget's philosophy. According to Piaget, if the experimentation matches their currently held beliefs then the experiences are assimilated. If the result of the experimentation does not match the currently held beliefs, then, the experience can either be discounted or accommodated by a conceptual change (p. 45). As per Llewellyn, "Assimilation is the filtering and integration of stimuli, concepts, and external elements within the context of existing knowledge and schema, whereas accommodation is the modification and adjustment of cognitive structures to new situations" (p. 45). Furthermore, equilibrium results when assimilation and accommodation work together.

During the Explanation phase of the lesson cycle, the students explain the results of their exploration. The teacher encourages the students to explain the concepts and/or definitions in their own words. The teacher uses the students' experiences in the exploration phase as the basis for explaining the concepts. During the Elaboration part of the lesson cycle, students apply their knowledge to a new situation. If a new experience matches a theory that they believe, the new experiences are assimilated and the schema or model is reinforced (p. 45).

During the Evaluation stage, the students answer open-ended questions to demonstrate their understanding and new-found knowledge. The teacher ascertains whether the students have changed their thoughts or behaviors. Students may also evaluate their own progress and knowledge and ask questions that would stimulate a new investigation (Lawson, 2002). An emphasis on metacognition – on helping students monitor, reflect upon, and improve their strategies for learning and problem solving – has also been shown to increase transfer (Bransford et al., 1999).

POTENTIAL ROADBLOCKS

Although the utilizing the scientific method as a way of obtaining scientific content knowledge seems feasible, there are several roadblocks to achieving this goal. Dewey (1938) argued that the school system is set up for a more traditional form of education with the patterns of the typical school consisting of exams, schedules, and bells within the school. Dewey stated the following about traditional education: "The subject matter of education consists of bodies of information and of skills that have been worked out in the past; therefore, the chief business of the school is to transmit them to the generation" (p. 17). In contrasting the traditional school with his progressive curriculum, Dewey contrasts the two schools in the following way:

> To imposition from above is opposed expression and cultivation of individuality; to external discipline is opposed free activity; to learning from texts and teachers, learning through experience; to acquisition of isolated skills and techniques by drill, is opposed acquisition of them as means of attaining ends which make direct vital appear; to preparation from a more or less remote future is opposed making the most of the opportunities of present life; to static aims and materials is opposed acquaintance with a changing world. (p. 20)

Another barrier to implementing inquiry lessons is that the teacher may have a difficult time letting go of the role of being the disseminator of knowledge because he/she has been inducted into that mode by his/her education and is expected to play that role by those directing educational policy at school district, state, and national levels. Many teachers have pre-conceived notions regarding a proper class based on their own experience as a student. "Teachers tend to teach as they were taught. If they were taught through lecture, they are likely to lecture, even if such instruction is inappropriate for their students" (McDermott et al., 2000, p. 412).

Another potential roadblock to teaching through inquiry is the lack of preparation of the teacher. In order to teach effectively, teachers must possess a strong background in science content as well as learn new methods of teaching that will cultivate conceptual development of science concepts with their students. Much research has been done as to how students best learn science concepts. Active engagement in the learning process has always been crucial to concept development which was also emphasized by Dewey, Schwab, and Piaget. Inquiry lessons coupled with constructive discussion among students in collaboration with the teacher help students cultivate connections between ideas; however, facilitating inquiry-based lessons requires the teacher's in-depth knowledge of the subject area. Perhaps Dewey's pedagogy would be more prevalent in today's curriculum if the drive to create standardized knowledge statements (standards) and standardized testing—both of which rely on formal knowledge claims, had not put a halt to his ideas, which also took into account personal expressions of knowing. As Kliebard (2004) explains:

> The rise of standardized achievement tests in the twentieth century would sharply accelerate the tendencies in the teaching of the three R's that he so much deplored and would help make his own emphasis on the relationship between reading and human purposes of the object of scorn and caricature. (p. 68)

Since most high stakes tests are made from educational standards, the vicious cycle of standardized tests is reducing the quality and quantity of education offered to the children of Texas with the most damaging effect on minorities and low socioeconomic youth (McNeil & Valenzuela, 2001, p. 2). Studies have shown the high stakes testing in general have had a detrimental effect on our education system. As indicated by Nichols and Berliner (2005), implementing high stakes testing has negatively impacted every level of the public school system. Moreover, teachers are not empowered to play an integral part of informing the curriculum. Darling-Hammond (1997) asserts that "A coherent view of curriculum, assessment, and teaching is at the core of any vision of more effective education" (p. 211). While this may be true, in the United States educational system the profession has turned into a huge bureaucracy where teachers have little or no say on "standard setting, curriculum development, or assessment" (p. 213). This vicious cycle of curriculum design and power is well documented throughout history. Dewey also felt the disconnect associated with developing standards, curriculum, and assessment.

> Every movement for change, whether it be a new way of teaching arithmetic of a new subject such as manual training, is seen as isolated and independent from the rest of the curriculum; what we have is a multiplicity of standards for judging the worth of each reform, and the standards can easily work at cross-purposes. (as cited in Kliebard, 2004, p. 74)

Dewey also called attention to "the mechanics of school organization and administration" that they often control what gets taught (p. 74).

Is our educational system doomed? Why should we continue to spend money and resources on professional development when teachers are unable to apply what they learned in the classroom or have any say in curriculum writing? The classroom is where the research, collaboration, and curriculum planning should take place. According to Clandinin and Connelly (1992), the teacher, researcher, and curriculum specialist must work together and all be equal in the process in order for curriculum writing to be successful. Additionally, collaboration must occur and must take place in the classroom. As Clandinin and Connelly note,

> The future direction for the teacher as curriculum maker is an agenda shared with teachers. It has two parts: to listen to teachers' stories of their work and to construct together stories of teachers as curriculum makers. Both parts send us back to the classroom to listen to teachers' stories of their work. (p. 392)

Effective research can impact our educational system and inform practice if the teacher is an integral part of the process; however, as Dewey purported, "as long as the system of rewards remain the same, the reform is doomed" (Kliebard, 2004, p. 74). Schwab (1983) viewed teachers as "the fountainhead of the curriculum decision" because only he/she meets the students face-to-face. To him, "there are a thousand ingenious ways in which commands on what and how to teach can, will, and just be modified or circumvented in the actual moments of teaching" (p. 245). In Schwab's words,

> Teachers practice an art. Moments of choice of what to do, how to do it, with whom and at what pace, arise hundreds of times a school day, and arise differently every day with every group of students. No command or instruction can be so formulated as to control that kind of artistic judgment and behavior,

> with its demand for frequent, instant choices of ways to meet an every varying situation. (p. 245)

Schwab believed it was necessary for teachers to be involved in decisions regarding what must be taught and how it should be taught.

Teacher as Curriculum Maker vs. Teacher as Curriculum Implementer

Although we all start with a set of standards and/or curriculum from which to teach, can a teacher make the curriculum work for his/her own students—that is, tailor the lived curriculum to meet his/her students' needs? Many teachers are given a binder with a complete curriculum document to implement in their own classroom. Those teachers that take into account their students and their environment while deciding how to teach a particular concept act as curriculum makers. "The teacher as curriculum maker image works from the assumption that a classroom space exists within which teachers and students negotiate curriculum unhampered by, though not oblivious to, others' mandates and desires" (Craig, 2010, p. 868). "It is a view in which the teacher is seen as an integral part of the curricular process and in which teacher, learners, subject matter, and milieu are in dynamic interaction" (Clandinin & Connelly, 1992, p. 392). In Craig's view (2010),

> Teacher as a curriculum maker is an image that acknowledges the teacher as a holder, user, and producer of knowledge, a self-directed individual who takes the curriculum as given and negotiates it in active relationship with students to address their needs as learners and, to the extent possible, meet the requirements outlined in stated curriculum documents. (p. 867)

Those teachers that merely execute the curriculum as stated are known as curriculum implementers and are described as follows:

> In the [teacher-as-curriculum-implementer] conceptualization, the teacher uses other people's knowledge and, in a technical rational way, installs a curriculum/curriculum package designed by others. In short, the image of teacher as curriculum implementer treats teachers as functionaries who are totally reliant on state and national imperatives. (Craig, 2010, p. 869)

For curriculum making to occur, Schwab (1960/1978a) maintained that there are four bodies of experience that must be represented. These four commonplaces include the following: subject matter, learners, milieus, and teachers. As Craig explains (in press):

> Curriculum is what happens – what becomes instantiated – in the moments when teaching and learning fuse. In that fusion, teachers use what is in their students (learner commonplace), their teaching situations (milieu commonplace) and themselves (teacher commonplace) to make curriculum (typically organized around the subject matter commonplace) in a way that cannot be captured in a codified knowledge base without negating the continuity of experience (Dewey, 1938) fueling the human knowing. (p. 2)

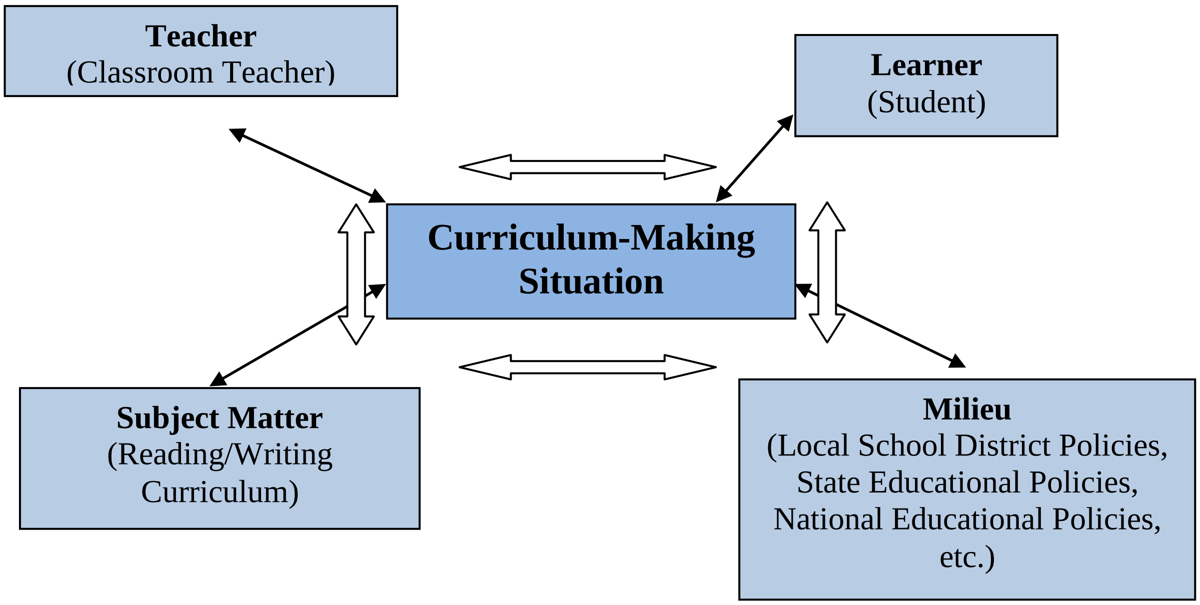

Figure 1. Schwab's curriculum commonplaces (Craig in press).

In my study, teachers are involved in professional development. Hence, the commonplaces become subtly altered with the teachers becoming learners and the professional developers becoming the teachers. The subject matter also changes as physics content as a school subject and pedagogical approaches to teaching physics through inquiry methods share the limelight. Additionally, general pedagogical knowledge (i.e., group work strategies, sharing of laboratory equipment) is discussed and made explicit.

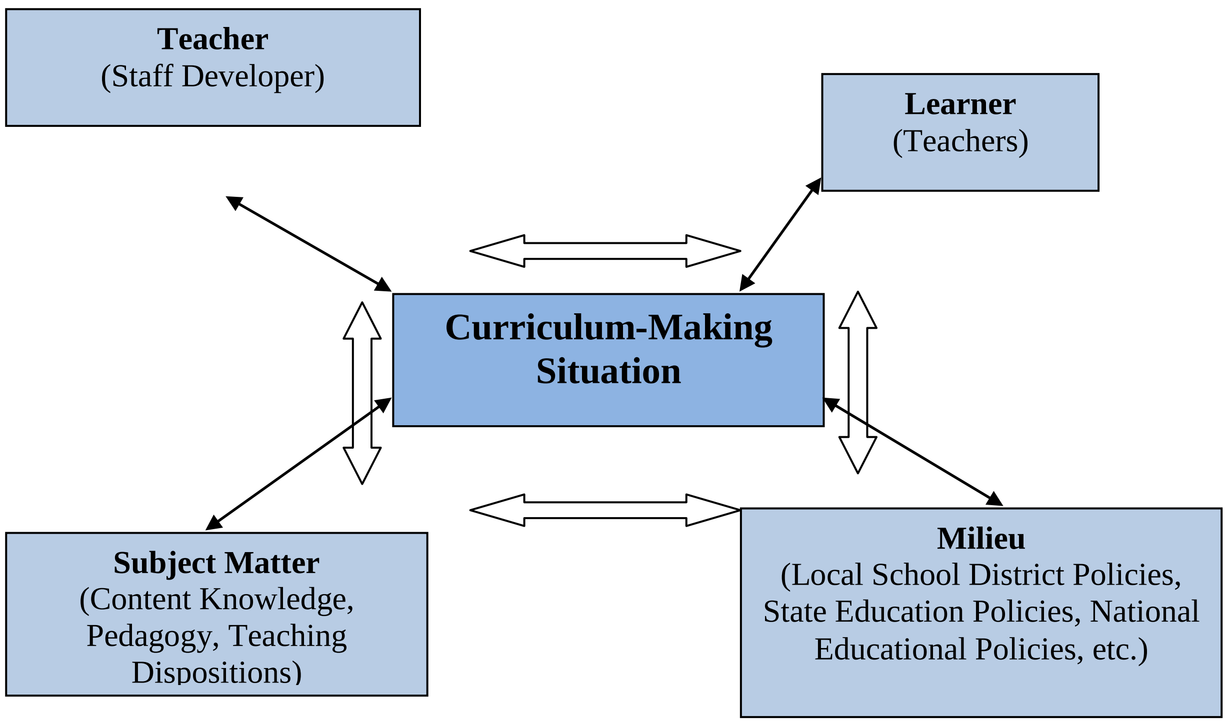

Figure 2. Changes in the commonplaces of curriculum configuration (Craig in press).

As Craig (in press) has explained, "This re-configuration of the curriculum commonplaces places the teacher in the vulnerable role of adult learner this time around and once again shines the spotlight on the teacher-learner relationship" (p. 8). Additionally, if the professional developer expects the teachers to replicate what is learned in the professional development without taking into consideration his/her students and milieus, then the teachers would take the role of a curriculum implementer. To Craig, "the training mindset reduces the teacher as a human being to the mundane, repetitive role of a human doer whose doings are directed by others" (p. 8).

Although many teachers may be prepared to make the curriculum their own, they may experience different challenges depending on their experience and the supports that are in place at their respective schools. As part of the physics inquiry course, teachers will develop lessons that will take into account their students and milieus. In short, they will develop lessons that will work in their own classrooms contexts shaped by particular social-cultural forces and the particularities of their students as learners.

The National Science Education Standards (NSES) (NRC, 1996) established specific standards for the professional development of science teachers and advocate the following:

> Professional Development Standard A: Professional development for teachers of science requires learning essential science content through the perspectives and methods of inquiry. (p. 59)
>
> Professional Development Standard B: Professional development for teachers of science requires integrating knowledge of science, learning, pedagogy, and students; it also requires applying that knowledge to science teaching. (p. 62)
>
> Professional Development Standard C: Professional development for teachers of science requires building understanding and ability for lifelong learning. (p. 64)
>
> Professional Development Standard D: Professional development programs for teachers of science must be coherent and integrated. (p. 67)

In the physics as inquiry course, teachers will learn physics content through the inquiry method, which reaches back to Dewey and Schwab, among others Additionally, teachers will have the opportunity to discuss the pedagogy and develop lessons for their own classrooms in a manner consistent with Schwab's 'practical' orientation.

To analyze the value of using this model of inquiry as a vehicle for teaching in the classroom, conversations, journals, focus groups, work samples, and surveys will be evaluated which will be the basis of this narrative inquiry. Teachers will have the opportunity to present their ideas during the final day of the course and share their lessons with the group so that the entire group will have a bank of lessons to include in their repertoire.

The results of this both the physics inquiry course and professional development sessions will be analyzed to determine the influence of using the inquiry method for teacher learning and to ascertain whether the teacher participants will be more apt to employ the inquiry method in their own classrooms subsequent to these experiences. Additionally, the extent to which they teach science as inquiry in their own classrooms and the barriers and promoting powers they meet as they endeavor to do so will also be part of this study.

SUMMARY

In Chapter 2, I have researched literature to address the main pillars in my inquiry. I began with the common misconceptions that both teachers and students possess regarding heating and temperature so that I can determine whether or not learning physics content as inquiry will address these misconceptions. Additionally, I have focused on the area of science/physics reform and science inquiry in order to address pedagogical knowledge in which to situate the physics inquiry course and professional development initiative, which aims to help teachers become more adapt in teaching science as inquiry. I also researched potential stumbling blocks that teachers may encounter on their journey to transforming their traditional classrooms into inquiry classrooms. My final concept, the image of teacher as a curriculum maker vs. teacher as a curriculum implementer, was included to show the characteristics of each and to discover what needs to be taken into account when teachers live physics curriculum alongside their students in particular classroom settings. Chapter 3, which follows, will outline the methodology utilized in this inquiry into inquiry.

CHAPTER THREE: METHODOLOGY

INTRODUCTION

The purpose of this study is to determine the change of teachers' physics content knowledge and personal practical knowledge after participating in a graduate level physics inquiry course and subsequent professional development throughout the school year. In addition, teacher participants will be studied to determine the roadblocks they encountered when they took curriculum mandates and altered them in ways that would allow them to utilize the inquiry method. The results of this study will be analyzed to inform my personal practice of preparing undergraduate science teachers as well as continuing to work with in-service teachers in the *teach*HOUSTON program. It is entirely possible that, if teachers are more apt to teach science as inquiry following this course and professional development, a semester long physics inquiry course will be added to the *teach*HOUSTON sequence of courses.

In order to study curriculum, Schwab's (1966) fours commonplaces of curriculum must be taken into account. As Schwab (1973) declared, "Defensible educational thought must take account of four commonplaces of *equal* rank: the learner, the teacher, the milieu, and the subject matter. None of these can be omitted without omitting a vital factor in educational thought and practice" (pp. 508-509). During the physics inquiry course, these commonplaces become altered as teachers became learners and I, the professional developer, became a teacher of teachers. Additionally, the subject matter consists of physics content as well as pedagogical knowledge. However, during the observations of teachers in their classrooms, the teachers will resume the traditional role of the teacher while I will fade into the backdrop and become part of their milieus as a classroom observer.

PURPOSE

Although teaching science as inquiry has been recommended by a myriad of resources (National Research Council [NRC], 1996, 2005; American Association for the Advancement of Science, 1993; National Academy of Sciences, 2007), the majority of teachers fail to employ inquiry teaching methods to their teaching repertoires (Salish I Research Collaborative, 1997). Even when preservice and in-service mathematics and science teachers are trained in "best practices," many resort to teaching in ways that conflict with this preparation. In fact, many teachers resort to teaching the way they were taught (McDermott, 2007; Olson, 1995; Pereira, 2005; Windschitl, 2002). As a result, teachers will be taught physics content through the process of inquiry in order to change their mental models of what an effective classroom should look like. However, will teachers subsequently employ science inquiry in their own classrooms? Are there barriers that teachers encounter while trying to create science as inquiry lessons for their own students?

NARRATIVE INQUIRY

This study is an inquiry into the narratives of three teachers who all teach science in public schools in the fourth largest urban center in America. These stories will express the experiences teachers live while co-constructing the daily curriculum with their students and will form the primary data source for this study. This research is grounded in the method of narrative inquiry (Clandinin & Connelly, 1992, 2000; Craig, 2011; Polkinghorne, 1995).

Narrative inquiry is strongly influenced by John Dewey (1938) who believed that one must rely on past experiences and knowledge to solve problems and that life experience is in fact education. Furthermore, Clandinin and Connelly (2000) purport that "Experience happens narratively. Narrative inquiry is a form of narrative experience. Therefore, educational experience should be studied narratively" (p. 19). They go on to give some characteristics of narrative inquiry.

> Narrative inquiry is a way of understanding experience. It is a collaboration between researcher and participants, over time, in a place or series of places, and in social interaction with milieus. An inquirer enters this matrix in the midst and progresses in this same spirit, concluding the inquiry still in the midst of living and telling, reliving and retelling, the stories of the experiences that make up people's lives, both individual and social. Simply stated, narrative inquiry is stories lived and told. (p. 20)

I will be relying on teachers to tell their stories as they work on making their curriculums work for their classes in an attempt to understand their experiences. Clandinin and Connelly explain that process of narrative inquiry involves "a collaboration between the researcher and the participants, over time, in a place or series of places, and in social interactions and with milieus" (p. 20). As maintained by Clandinin and Connelly (2000),

> The phrase experience the experience is a reminder that for us narrative inquiry is aimed at understanding and making meaning of the experience. This is the baseline "why" for social science inquiry. Why use narrative inquiry? Because

> narrative inquiry is a way, the best way we believe, to think about experience. (p. 80)

Torbert (1981) among others is a proponent of collaborative inquiry and gives several justifications as to why this particular model is more effective. Unlike the unilateral control model, in the collaborative inquiry model the research and action are intertwined in practice. The researcher is an interactive participant, not a detached observer. Therefore, change could transpire through dialog between the actor-researcher and others. Moreover, the researcher is able to test theories in action as a result of being both the researcher and participant.

Reflecting on my own professional practice, I realize that a model of collaborative inquiry served as a stimulus for changing my own physics curriculum from a more deductive model to one that is inquiry-based. The impetus for this change was participating in Japanese Lesson Study (Lewis, 2000) which is an instrument to enrich teaching; to focus on the learning that takes place rather than the content; and to ascertain how to facilitate students' learning. In this regard, lesson study can be a powerful tool for change for all educators. The four main parts of lesson study are collaborative planning, lesson observation by colleagues and guests, analytic reflection, and ongoing revision (Curcio, 2003, p. 23). This parallels collaborative inquiry in that the researcher is an integral part of the research and collaborates with colleagues to inform their practice. According to Torbert (1981), "each actor can gain increasingly valid knowledge of social situations only as other actors collaborate in inquiry disclosing their being, testing their knowledge, discovering shared purposes, and producing preferred outcomes" (p. 147). I learned how valuable this process was in informing practice and that it was the rich collaboration with colleagues that had the most significant impact on improving our curriculum.

Collaborative inquiry can be a powerful tool for teachers to inform their practice; however, teachers must first be empowered to play an integral part of informing the curriculum. According to Clandinin and Connelly (1992), the teacher, researcher, and curriculum specialist must work together and all be equal in the process in order for curriculum writing to be successful. Additionally, collaboration must occur and must take place in the classroom. Clandinin and Connelly explained the following:

> In our view, the future direction for the teacher as curriculum maker is an agenda shared with teachers. It has two parts: to listen to teachers' stories of their work and to construct together stories of teachers as curriculum makers. Both parts send us back to the classroom to listen to teachers' stories of their work. (p. 392)

In short, the classroom is where the research, collaboration, and curriculum planning should take place.

Narrative inquiry occurs within a "*three-dimensional narrative inquiry space*" which allows us to travel in the following directions: "inward, outward, backward, forward, and situated within the place" (Clandinin & Connelly, 2000, p. 49). This narrative inquiry meets the above criteria in that I will travel inward to study the personal feelings of myself and the participants; outward in that I will take into account the environment that each participant encounters while teaching; backward, forward, and situated within the place in that I will take into account the past, present, and future while studying different events. This inquiry will take me back to my personal experience of learning physics through the process of guided inquiry and how I was able to enact this pedagogy in my own classroom. The present will be studied as teacher participants learn physics content through inquiry and change their curriculum to reflect inquiry-based learning. The future will be discussed as I reflect on how to incorporate what I have learned to strengthen my own practice.

Qualitative research is typically a fluid inquiry as one follows the data down a path that is not predetermined. Investigations, whether scientific or educational, take on two forms of inquiry, stable inquiry and fluid inquiry (Schwab, 1960, p. 15). Stable inquiry lends itself to investigations that proceed in a linear, step-by-step approach that lead to the verification of facts already known. In science, it is known as a verification lab or a cookbook lab. Typical science curriculums are riddled with cookbook labs in which the students follow a set of instructions that inhibits their thinking and ability to bring meaning to the science concept they are studying. A fluid inquiry does not follow a linear approach; it is not governed by theories, methodological tactics, and strategies (Clandinin & Connelly, 2000, p. 121). During the course of this study, teachers will be encouraged to change their existing cookbook labs to those in which the students set out to discover relationships between variables and construct new knowledge. Because each student comes to the classroom with differing previous experiences, students may subsequently choose different paths in which to formulate their own mental models of physics concepts. Similarly, my own study will be fluid in that my participants bring diverse experiences and backgrounds to the physics inquiry class. Fluid inquiry allows the researcher to follow the data which may lead down a twisting path. As per Schwab, "Its immediate goal is not added knowledge of the subject matter, per se, but development of new principles" (p. 17). This applies to my research in that I am not sure of the outcome of this narrative inquiry or the path that I will follow as I co-construct the stories with my participants. Just as many of my physics lessons have deviated from my lesson plan based on my students and their backgrounds, this inquiry may also take on a path determined by the experiences of the participants.

PHYSICS INQUIRY COURSE AND PROFESSIONAL DEVELOPMENT

Overview

A graduate level course was developed using McDermott's *Physics by Inquiry Volume I* (McDermott, 1996) as a resource and model for teaching teachers.. Utilizing this type of teacher professional development is designed to augment the content knowledge of the teachers on a deeper level while allowing teachers to experience the process of inquiry learning. It is anticipated that teachers will be more comfortable with this model of teaching and better prepared to employ this method of teaching in their own classrooms. The graduate course and professional development sessions were facilitated by two science master teachers from the *teach*HOUSTON program. The *teach*HOUSTON program is a secondary science and mathematics teacher preparation program at the University of Houston and is modeled after the UTeach program at the University of Texas in Austin which has become a national model for teacher certification. *Teach*HOUSTON is the first replication site out of 22 sites across the country and was originally funded by a grant from the National Math and Science Initiative. It is a collaborative project of the University of Houston's College of Natural Sciences and Mathematics, the College of Education, and local school districts. The goal of the *teach*HOUSTON program is to increase the number of math and science teachers in high needs areas of the state who exhibit both a deep understanding of secondary level mathematics and science content as well as the knowledge of curriculum development and instructional strategies.

Participants

Seventeen certified science teachers ranging from 3 – 28 years of teaching experience attended the physics inquiry course at the University of Houston in Sugar Land during the summer of 2010 and professional development sessions which are ongoing throughout the 2010-2011 school year. Ten of the teachers teach middle school science, six teachers teach high school science, and one teacher teaches fifth grade science. This graduate level course is part of a Teacher Quality Grant whereby teachers chosen teach in high needs schools as determined the Texas Education Agency's Academic Excellence Indicator System (AEIS). Teachers selected were given a stipend and graduate credit for attending the physics inquiry course and subsequent professional development sessions throughout the year.

Physics Inquiry Course Description

Prior to embarking on the content portion of the physics inquiry course, an Inquiry-Based Instruction Survey, adapted from Marshall and Petrosino (2010), was given to participants to ascertain their attitudes regarding inquiry-based instruction including potential barriers to enacting inquiry lessons in their own classrooms. The full text of the Inquiry-Based Instruction Survey is given in Appendix A.

The goal of the first two days of the course was to investigate principles of matter. This portion of the class was essential for teachers to solidify concepts of mass, volume, and density before delving into temperature and heating. Both pre-tests and posttests were given to the participants to ascertain understanding of the principles of matter.

Three days were devoted to heating and temperature which is the emphasis of the content portion of this research. A temperature and heating pre-test was administered to the participants before going through the heating and temperature modules. Questions asked were open-ended and included explanations based on their experience with these topics. The pre-test and posttest were identical and contained eight questions, three which will be the focus of the content portion of this research. The pre-tests and posttests were largely adapted from an article by Harrison, Grayson, and Treagust (1999) in which research was done over students' ideas of heating and temperature. Some questions were added by the facilitators to pinpoint misconceptions. The full text of the pre-tests and posttests is available in Appendix B.

Teachers completed the modules in groups of two or three. A typical module had teachers perform experiments, make predictions as to the outcome of the experiment, as well as answer probing questions to analyze results. This is in line with Schwab's (1962) beliefs that science should be learned similar to the way that scientists conduct their research. Additionally, teachers had to periodically check their answers with an instructor. At this point the instructor would ask each participant probing questions to determine achievement of the objective. If participants were headed down a different path than intended, scrutinizing questions were asked to foster discussion and understanding of the concepts. This type of professional development is designed to meet the needs of the individual teachers and to build on their prior knowledge of the subject matter. Many professional developments do not take an individual approach but tend to take on a "one size fits all" approach (Craig, in press, p. 4).

> Such one-size-fits all sessions typically do not build on what individual teachers already know and do. Instead, teacher professional development is approached generically – as if all teachers suffer the same malady and need to be injected with the same antidote. Even more troubling is the underlying belief that teachers' knowledge is deficit and not simply needing further cultivation, but requiring total replacement. (p. 4)

Each teacher attending the physics inquiry class came to the course with a varying background and education in science. Some came to the class without taking a prior physics course while others came to the course with one or two college courses in physics. Additionally, the experience the teachers have in teaching physics concepts to their students varied with their years of experience and the grade level/subject matter that they teach. As a result, it was imperative to build on each teacher's education and experience level and cater to the individual teacher so that he/she would build on their own foundation which would provide a richer experience. To treat each teacher as if they were starting without any prior knowledge of physics content or personal practical knowledge would diminish the years of teaching experience, experiential knowledge teachers came to know while students, and could result in a mediocre course. As a result, the physics inquiry course was designed for teachers to complete at their own pace. Additionally, teachers worked through the modules in such a way that they constructed their own knowledge as a result of experimentation and discussions with their group members and the facilitators.

Teacher and instructor discussions included questions over concept development as well as personal knowledge including how these modules might be beneficial in their own classrooms in that they would take into account their own students and milieus. Furthermore, other activities were enacted when needed to reinforce content or unpack knowledge of content and context. Periodically, when the instructors encountered a topic that was a stumbling block for most groups, the entire group of teachers would have a fruitful discussion as to why the concept was particularly difficult to grasp and how it could be applied in their classrooms.

Gathering Data (Stories)

To gather meaningful data, both pre-tests and posttests were scored and analyzed for common themes and misconceptions. Additionally, the manuals were copied in which participants answered questions, made graphs, analyzed data, and developed conclusions regarding these topics. Participant journal reflections and conversations will be analyzed to analyze the value of using this model of inquiry as a vehicle for teaching in the classroom. Moreover, participants developed two lesson plans to utilize in their classes for the 2010-2011 school year which will be analyzed to ascertain the whether or not the physics inquiry graduate course impacts their own practice.

On-Going Professional Development

Subsequent to the physics inquiry graduate course, six professional development sessions will occur throughout the 2010-2011 school year to support what was learned in the physics inquiry course. Topics include the following: science literacy, physics inquiries, chemistry inquiries, unpacking personal practical knowledge, and ongoing lesson plan development. Conversations, journal entries, and lesson plans will be analyzed to determine whether the physics inquiry course impacted their attitudes and practice. Additionally, barriers and tensions to changing their teaching practices will be analyzed and addressed.

Procedures/Tools – Data Collection

I, the researcher, will be the instrument that will bring the data together and thread it. I will utilize a variety of tools in this study. As per Clandinin and Connelly (2000), field texts are one of the primary tools for collecting data in narrative inquiries which are typically known as data. "We call them field texts because they are created, neither found nor discovered, by participants and researchers in order to represent aspects of field experience" (p. 92). In this inquiry, I will utilize a variety of field texts that include autobiographical writing, conversations, journal writing, field notes, correspondence, direct observations, documents, and life experience. Below I describe the roles that each of these field texts play in this inquiry.

I have utilized autobiographical writing as I have written about my past history as both a learner an educator. I have looked back upon my own life and my experiences that have led me to study science as inquiry and also to understand my own teaching practice.

My goal is to improve my own practice which will in turn lead to improvement in my working with both preservice and in-service teachers.

Conversations regarding this inquiry are numerous and ongoing. Some of these conversations were captured in my journals while others undoubtedly will influence my thoughts and ideas for this inquiry. I have conversed with my both my colleagues and former colleagues, preservice and in-service teachers, friends, family members, as well as professors of education and physics at the University of Houston and other universities. These conversations have broadened my thoughts in that they have assisted me in looking at alternative points of view.

I have kept a journal which dates back to my master's program in which I was a student in the Physics by Inquiry Course in 2005. Journaling has helped me to capture my thoughts as I was able to gain a deeper understanding of physics as it was taught through the guided inquiry pedagogy. Subsequent journal entries describe my thoughts as I incorporated more inquiry units into my own physics curriculum. I have continued to journal throughout my doctoral program and many of my journals describe my thoughts as I teach my preservice and in-service classes in science education. I have shared these stories with my students in an attempt to impact their practice. In the article, *Becoming a Teacher of Mathematics*, Pereira (2005) examines how his deep-rooted experiences as a learner and teacher impacted his own practice in an emotional dimension. Pereira believes that sharing personal stories has the potential to reform mathematics education. "Sharing these tensions with mathematics teachers has had an impact on the way teachers talk about their teaching and promised to change how they teach" (p. 69). When discussing the impact that journaling can have on informing practice, Pereira states the following:

> It is remarkable how powerful such feelings are and how much they inhibit students from engaging with mathematics. It is also remarkable how liberating it can be for them to write about these feelings and to discuss their autobiographies with others. (p. 70)

In reflecting on his own teaching practice, Pereira realizes that if he expects his students to confront their own emotions about learning mathematics on a deep level, he must share his personal stories with his students. He analyzes his personal experiences as a learner and teacher through his stories which exposes the personal dilemmas he encounters when he teaches. "Stories have been an important vehicle through which I have explored the emotional dimensions of my own teaching and focused on the internal tensions that are created when my feeling and my needs interact" (p. 81). Pereira believes that by sharing his personal experiences, his students will reflect on their own experiences in a much deeper level which will in turn help his students live with the emotions surrounding teaching they possess. While working with teachers in professional development, I have shared my stories of learning physics through inquiry with my students. Additionally, teachers have shared their learning experiences with others so that they may begin to change their vision of what a proper physics classroom should look like.

Field notes were recorded each day that the class was in session. I recorded these as soon as the class was over to capture my thoughts and feelings regarding each class. Additionally, I will take field notes during my observations of teachers teaching their inquiry-based lessons and subsequent to each classroom visit. These field notes will provide me with detailed notes of what was occurring in each class during my observation.

Much of the correspondence with the teacher participants has and will occur via email, texting, and blackboard. Many of the participants would send me their lesson plans and also ask for advice about certain portions of their lesson plans. Also, many of the participants have invited me out to visit them in the field.

Direct observations of science lessons will be conducted. Teachers will be observed several times throughout the year and notes will be taken that describe the teacher's transmission of the content and pedagogy. Additionally, a discussion with each teacher will occur before and after the observation. The observations will be focused on both content and knowledge to ascertain whether or not teachers were teaching science as inquiry.

Several documents will be gathered throughout the study which will consist of the following: course syllabus, pre-tests, posttests, lesson plans, pre/post surveys, assignments, and handouts. These artifacts will be useful in that I will be able to analyze the improvement in content as well as in the dispositions that participants have regarding teaching science as inquiry.

My life experience will also be considered as a field text as I am facilitating this physics inquiry course in that I was once a participant in a similar course. As per Clandinin and Connelly (2000), "Reserachers' personal, private, and professional lives flow across the boundaries into the research site" (p. 115). Stories and experiences both past and present may be connected to the stories of the participants. Moreover, telling stories of ourselves may lead to restorying.

> As we worked within our three-dimensional spaces as narrative inquirers, what became clear to us was that as inquirers we meet ourselves in the past, the present, and the future. What we mean by this is that we tell remembered stories of ourselves from earlier times as well as more current stories. All of these stories offer possible plotlines for our futures. (p. 60)

Table 2 depicts each data collection strategy, the frequency of each strategy and the number of participants that participated in each strategy. Most of the participants took the inquiry-based instruction surveys and the pre-tests and posttests if they were in attendance on that particular day of the course. All participants completed the journal reflections, course manual, and turned in lesson plans. After carefully analyzing the data from the physics inquiry course, at least two participants will be interviewed and observed at their schools. Additionally, six teachers will participate in on-line focus groups throughout the 2010-2011 school year.

Table 2.

Data Collection, Frequency and Number of Participants

Table 2. Data Collection, Frequency, and Number of Participants		
	Frequency	Number of Participants
Inquiry-Based Instruction Survey	1	17
Inquiry-Based Instruction Post Survey	1	13
Journal Reflections	11	17
Pre-Test Heat and Temperature	1	14
Posttest Heat and Temperature	1	13
Course Manual	1	17
Observations	2	2
Interviews	3	3
Focus Groups	4	6
Lesson Plans	2	17

Figure 3 illustrates how each data collection device encompasses the research questions put forth by this study. Each research question is addressed by at least five data collection tools.

Research Question	How does learning through inquiry impact the quality/quantity of physics that is learned?	How does learning physics through inquiry impact the attitudes that teachers have toward teaching through inquiry?	Are teacher participants more apt to employ inquiry learning subsequent to learning science as inquiry?	What are some of the roadblocks teachers encounter in their experiences of trying to teach science as inquiry?
Inquiry-Based Instruction Survey		✓	✓	✓
Journal Reflections	✓	✓	✓	✓
Pre-Test Heat and Temperature	✓			
Posttest Heat and Temperature	✓			
Course Manual	✓			
Observations	✓	✓	✓	
Interviews	✓	✓	✓	✓
Focus Groups		✓	✓	✓
Lesson Plans	✓	✓	✓	✓

Figure 3. Data collection and analysis by research question.

Analytical Tools

I will use three modes of interpretive tools to support the narrative inquiry method which include broadening, burrowing, and storying and restorying (Connelly & Clandinin, 1990). Furthermore, fictionalization will be utilized to maintain the confidentiality of the participants. Because I am also a participant in this qualitative research, I realize that I must recognize the possibility for bias in my own study which may impact interpreting my results. Subsequently, I must be aware of my own subjectivity and manage this in my research.

First, I will use broadening as an interpretive tool to get an overall picture of the data. I will organize each participant's data into a binder. Each binder will include the following: Inquiry-Based Instruction Survey, Inquiry-Based Instruction Post Survey, Heat and Temperature Pre-Test, Heat and Temperature Posttest, Physics Inquiry Manual, reading reflections, journal reflections, and lesson plans. Analyzing the data of all of the participants will allow me to obtain a general idea of how participants improved in their physics content and to also ascertain general themes that emerge during their journal reflections. It is anticipated that by analyzing all of the data, I will be able to focus on specific content questions and determine which participants to include in the narrative inquiry.

My second interpretive tool that I will utilize is burrowing in order to closely analyze the experiences and stories of two chosen participants. I will focus in on particular experiences and analyze them for larger meanings they bring to bear on the study. I will show how the physics content and personal practical knowledge emerges from each participant and also to try and make sense of the experiences of the teachers and how this will translate into the context of their classrooms.

The third interpretive tool I will utilize will be storying and restorying. By analyzing each individual binder of data, I will look for narrative threads of experience that convey the journey that each participant goes through as a result of their experience in the physics inquiry class and professional development. Throughout the year, these stories may be restoried as observations, focus groups, and interviews take place of the two participants chosen. As Connelly and Clandinin (1990) maintain, it is difficult to understand and depict the stories as they change over time.

> We are, as researchers and teachers, still telling in our practices our ongoing life stories as they are lived, told, relived and retold. We restory earlier experiences as we reflect on later experiences so the stories and their meaning shift and change over time. As we engage in a reflective research process, our stories are often restoried and changes as we, as teachers and/or researchers "give back" to each other's way of seeing our stories. I tell you a researcher's story. You tell me what you hear and what it meant to you. I hadn't thought of it this way, am transformed in some important way, and tell the story differently the next time I encounter an interested listener or talk again with my participant. (p. 9)

Participants' stories may change as their experiences change. However, it is essential that the stories of the participants convey the truth of the story at that particular time and that truth can change with time and with context. Selections included in each participant's story will be of pivotal moments where the participant encountered a breakthrough in their way of thinking about the physics content or way of teaching science in their own classroom. Additionally, stories where the participants feel strongly about aspects of their classroom dynamics or roadblocks they encounter while on their professional journey will be included.

In order to protect the participants, personal names of participants, colleagues, schools, and districts names were given as pseudonyms to safeguard the individuals from any potential difficulties that could arise. Before participating in the study, all participants gave permission for the use of their stories. Each research participant was asked to sign an informed consent to assent to their willingness to participate in the study. They were informed about the nature of the inquiry and also of their right to withdraw from the study at any point in time. After the participants' stories were written, I gave each participant the opportunity to read their story to determine whether I wrote a fair and accurate description of their story.

In chapter four, I give an overview of three select content questions from the heating and temperature section of the physics inquiry pre-test and posttest of all of the participants to determine the growth in content and the benefits of teachers learning physics as inquiry. Additionally, I analyze the field texts, journals, and conversations from the content portion of the class to determine the overall effectiveness of utilizing inquiry as a vehicle for teaching in the classroom. Subsequent to an overall analysis, I selected two participants to focus in on how they made sense of the physics content, how they were able to implement inquiry into their own classrooms, and how they overcame or did not overcome the barriers to implementing inquiry lessons. The stories of the two selected participants are the main focus of this narrative inquiry.

CHAPTER FOUR: NARRATIVE STORIES

OVERVIEW

Having mapped my research method in Chapter 3, I analyze my field texts through turning them into research texts in Chapter 4. In this chapter, I particularly focus on my comprehensive analysis of the physics inquiry course followed by my presentation of the "stories of experience" (Connelly & Clandinin, 1990) that emerged from two participants, Anne and Stacy, who embraced inquiry-based learning as both teachers and learners. Anne's and Stacy's stories of learning throughout the physics inquiry course and subsequent professional development events depict ways in which they overcame barriers in their own mindsets and were able to transform what they came to know about inquiry into what they did in teaching practices and face-to-face interactions with students in their own classrooms. As the researcher, I existed as an additional participant in this study as the interviews and journal reflections of the two teachers revived my own memories of experiences related to understanding inquiry-based teaching and learning. I will include how both Anne's and Stacy's perceptions of inquiry changed throughout the year and the obstacles they faced in altering their practices and how this parallels my own past experiences and present experiences as a professional developer and science master teacher.

OVERALL ANALYSIS

To determine the value of using this model of inquiry as both a learner and also as a vehicle for teaching in the classroom, conversations, surveys, and journals from all seventeen participants were analyzed. Additionally, teachers gave a presentation on the last day of the course regarding how they would utilize what they learned in their own classrooms. In the post-course reflection, all of the participants listed the inquiry method of teaching as one of the most important elements they learned during the course. Many participants believed they learned content on a much deeper level when learning by inquiry. For example, one participant remarked, “To me, physics has been knowing the formulas to find out the answers. Through inquiry-based lessons, it becomes clearer as to how formulas are created and what each component really means.” Another participant wrote, “This approach to learning allows the student to reach a deep understanding of the concept without getting lost in the terminology or complexity of an equation.” When asked for the most valuable part of this experience, participants either mentioned or described the inquiry method and said they would employ the inquiry method in their classrooms; all participants mentioned that they expanded their content knowledge; and many mentioned the value of professionally and relationally interacting with other teachers and course instructors, Perri Segura and Paige Evans.

During the final day of the course, participants presented their ideas of what they would utilize from this course in their own practice. All participants mentioned a specific activity they could incorporate in their classrooms. Additionally, all participants felt more comfortable with this model of inquiry and saw the tremendous value when utilized as means for lesson enactment. One participant summed it up well when he observed the following:

> Inquiry is a way for students to learn a topic through self-exploration. The students will use a trial-error approach to really grasp a concept. With the inquiry

> approach, students get to really see what misconceptions that they experienced before the exercise. Their knowledge is a step-ladder that slowly builds till they reach the top of a topic.

What follows is the journey of two participants from the cohort, Anne and Stacy, as they first learned physics as inquiry and subsequently enacted inquiry-based learning in their own classrooms with the students before them.

NARRATIVES OF EXPERIENCE

Anne's Journey

Background

Anne came to teaching through a non-traditional path in that she did not complete an undergraduate program with education courses and students teaching. Anne did not realize that she wanted to pursue teaching until exploring her first career, archeology, and thus sought out alternative certification after obtaining her undergraduate degree. Anne was an archeology major in her undergraduate work as it was her lifelong dream to become an archeologist. In an interview, Anne recounted her high school experience which proved to later on influence her teaching:

> I was an above average student in high school who had almost straight A's. I took the highest courses my school had to offer. Science was the least favorite of all of my subjects because of all of the paperwork. It was taught in a lecture fashion with lots of paperwork. When I got to physics, it was the worst experience of all! It was boring and completely out of the book.

Later on in the interview, she recounts this physics experience when having to teach integrated physics and chemistry (IPC). She was determined not to have her less-than-positive high school physics experience ruin the experience for her students:

> When I learned that I would be teaching IPC, all of those memories came flooding back to when I was a high school physics student. I was determined to love physics so that my students might experience the same love. My students were not going to have the same experience that I did in high school. There is more to science than working out of a book and filling out worksheets.

Thinking back to my own experiences in high school, I have to say that my physics experience was also mediocre. I remember having multiple substitute teachers and not learning much of anything. The room always seemed noisy and out of control. In fact, nearly every day, someone would pull the handle on the chemical safety shower, which would flood the room with water. Like Ann, I was also determined to offer a different experience for my own students when I first started teaching physics. When asked what led to her success in school, Ann recounted her history teacher who had a huge impact on her learning. She said: “I had the same history teacher for three years in a row. The teacher told stories that were very exciting and did not lecture.” Anne’s recollection of her success in high school was integral as she realized that the traditional lecture method of teaching did not work for her.

Although Anne was successful in her archeology career, this path did not bode well with having a family and she decided to pursue teaching as a career instead. She was alternatively certified through a Texas alternative teacher certification program which took three months to complete. Anne described the following:

> It was practical in that you could quickly get certified; however, it was 'bare bones.' I did not learn anything about behavior control or how to get organized in the teacher sense. I did not really learn any teaching strategies. I basically learned to teach on my own through trial and error and did not really know what I was getting into with this profession.

Anne's first teaching job was at a middle school in the Houston, TX area. She described her first two years as "being thrown to the wolves" as she did not receive any support with curriculum, morale, or anything. She was basically left to figure it out for herself.

Readers will recall that I had a similar experience to Ann when I first started teaching middle school in Soledad, CA. The big difference was that I had several courses where I was able to teach in public schools prior to student teaching. I have no idea what it would have been like to begin to teach like Ann did without these foundational experiences, which were integral to my sense-making of teaching physics. It reminded me of a statistic that I recently came across in the Fuller Report (2009) where it showed how teachers that were alternatively certified were more likely to leave the teaching field within three years as compared to those who were traditionally certified to teach. I wondered whether getting certified from an alternative program augmented the difficulty Anne faced during her first few years of her teaching career since she did not have the experiences of those certified through traditional teacher preparation programs.

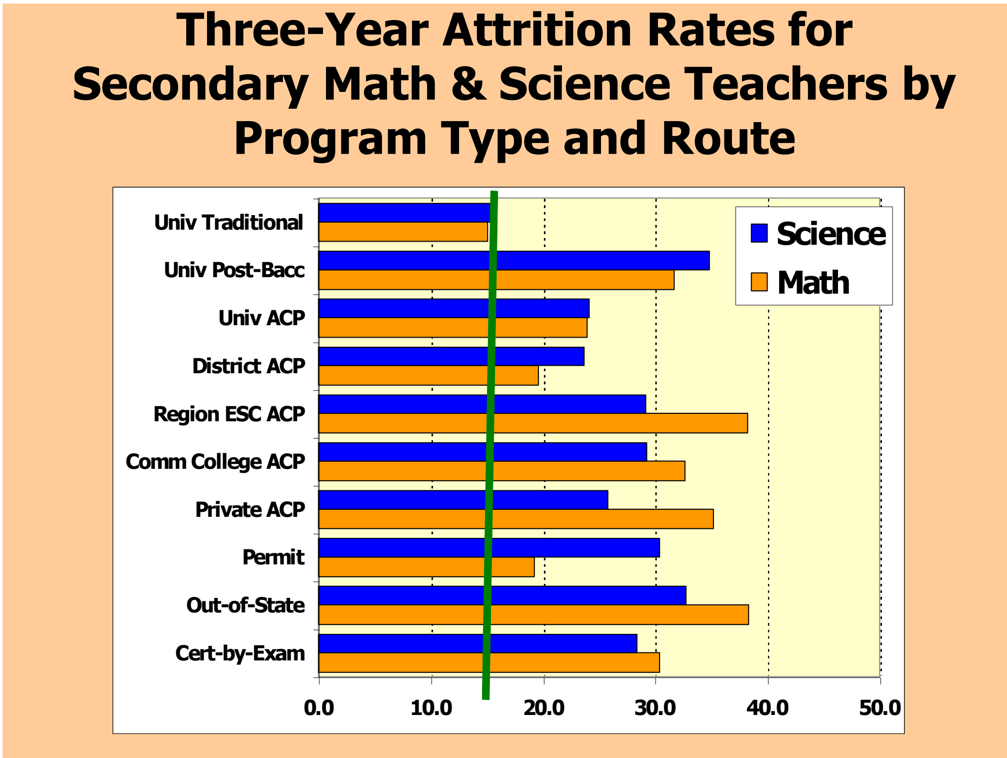

Figure 4. Three year attrition rates for secondary math and science teachers by program type and route (Fuller, 2009).

Subsequent to Anne's first teaching job, she was able to secure a position in her home town teaching a 7th grade Texas Assessment of Knowledge and Skills (TAKS) math class which consisted of 130 students who had previously failed the TAKS test. The TAKS test is a standardized test in Texas that is required under the Texas education standards and is utilized to assess students' attainment of reading, writing, math, social studies, and science. This high stakes test is given in science in grades 5, 8, 10, and 11in the state of Texas and students must pass the exit level (11th grade) test in order to graduate. Moreover, the results of the TAKS test factor into the accountability rating of schools and districts which is tied to monetary incentives. Teaching this class was a struggle in that she did not receive any support as far as advice, mentoring, or any type of curriculum in which to follow or modify. Before January rolled around, a regular 7th grade science teaching job opened up and Anne jumped at the opportunity to teach science since this was in her area of expertise. She reflected back on this experience:

> I really did not have any support at this school either. My department chair had been at the school for 40 years. In fact, my husband says that he is the epitome of the teacher that should retire. My department chair's teaching consisted of playing games on the computer. In fact, you could just look through the door and see what game he was playing at any period in the day. It was obvious that he did not have any interest in helping new teachers or his own students.

Although Anne did not have formal training in science education, she was determined to have a great learning experience for her students. In fact, she was the only science teacher that was meeting the 40% lab requirement from the TEKS objectives. Additionally, she was the only middle school science teacher with a background in science in her undergraduate degree. She believes this is why her principal requested that she teach 8th grade, which is tied to the science TAKS test. As Anne explained,

> the school relies on the pre/AP students to bring up the TAKS scores. Many of these students are from more stable families of a higher socio-economic status. These students are also afforded more opportunity. The school as a whole is very diverse and many of the students are from a low socio-economic background.

Even within a diverse school where approximately 60 % of the students are rated as economically disadvantaged, those of a higher socio-economic status end up with more opportunity as they are more apt to be in higher level courses with greater expectations and a more intensive curriculum. Furthermore, their parents are very involved in their child's education. This was contrary to my experience in that the entire school where I began teaching was composed of low socioeconomic students. The same was true of when I taught in Soledad, CA. Once again, accountability in the form of the TAKS test rose to the forefront and dictated the configuration of the school as far as who teaches what class and level.

In Anne's situation, the administration implemented a district-wide curriculum which was meant to be the magic bullet to fix everything. While many teachers were told to exclusively follow this curriculum, Anne was afforded the flexibility to use her own judgment in that she would follow the part of the curriculum that she felt would work well with her students. Because of Anne's success in the classroom, she was given permission to be a curriculum maker as opposed to a curriculum implementer (Craig, 2010). Anne described how she used the district-wide curriculum:

> I use the curriculum as a scope and sequence. I don't believe there is a magic bullet in education but it is a positive in that it guarantees that I at least teach the most important parts. It is also good for the elementary teachers and students because it forces them to do some science which was sorely missing in the past. The benefits, if any, will probably not be seen for 3-4 years.

Although it was beneficial to have a scope and sequence to follow, this also inhibited Anne from fully weaving inquiry into her curriculum in that it presented a time barrier, which she describes later throughout her experience of enacting science as inquiry into her own classroom. Anne also explained that since implementing the district-wide curriculum, the TEKS have changed and they have no new lessons to go along with the new TEKS. Only those teachers who act as curriculum makers took the time to write new lessons. The teachers that serve as curriculum implementers continued to follow the lessons in the mandatory curriculum even if the curriculum did not cover the new TEKS. Anne wrote the new scope and sequence for her grade level which is now followed by the other teachers.

Anne's Journey with the Physics Inquiry Course

Throughout her six years of teaching, Anne has sought ways to improve her craft. This is one of the reasons why she decided to participate in the physics inquiry course, which was funded by a Teacher Quality Grant. Readers will remember that participants received graduate level credit as well as a stipend for attendance. All of the teachers took a survey prior to embarking on the physics inquiry modules. Anne believed in theory that inquiry-based teaching was best for students; however, she did not believe it was feasible to enact this in practice. The following figure contains an excerpt from the survey:

Pre-Course Survey: Anne's Responses	
Question	What do you consider to be the key elements of inquiry-based instruction? In other words, how would you recognize inquiry-based teaching in a secondary science classroom?
Answer	Presenting a problem to the students and guiding them as they formulate a solution.
Question	Do you agree with the following statement? In theory, inquiry-based instruction represents best practices in secondary science instruction; all instruction should be done in this format.
Answer	Yes – I agree
Question	Do you agree with this statement? In practice, inquiry-based instruction represents best practices in secondary science instruction; all instruction should be done in this format.
Answer	Many students lack the prior knowledge or practical experience that is needed to tackle problem solving.
Question	Briefly describe how you plan to implement inquiry-based learning next semester (if at all). Please include the source for any curriculum materials you will be using.
Answer	I plan to have 2 – 3 labs weekly with students working in cooperative groups.
Question	What do you see as possible barriers to implementing inquiry-based learning into your classroom?
Answer	The students have absolutely no experience with this model. They are generally passive receptacles.

Figure 5. Ann's responses to the pre-course survey.

Subsequent to the survey and pre-test, the participants embarked on the physics inquiry modules in groups of 2 – 3 teachers. Teachers grouped themselves and most worked with someone from the same grade level or someone from their school. Anne worked with a colleague who also teaches 8th grade at her school. Anne and her partner worked through the modules which started out with assembling a balance, determining what mass is and experimenting with principals of balancing. Anne wrote the following notes to herself as the first day's activities unfolded. She wrote herself reminders and also posed questions as to how much guidance should be given to her own students which are shown below:

> The first activity is a rather clever method for introducing mass and conversions. Though some of the questions are repetitive and nonsensical, the past two sections would be a good way to get the kids to think about equivalencies in units. Simplify the assignment and shorten it. Provide more of the equivalencies. DO NOT help. Make them figure it out.

Here she was already questioning how she could make this work for her own classroom. She realized that her students are used to being told what to do and was not sure how to break this mold. The fact that she emphasized not to help the students shows up later in another obstacle that she continuously faces in that it is difficult to give up control and trust your students in the classroom. Anne continues:

> Setting up the stand would be the first obstacle. None of the students (pre-8th) have used a physics stand. Should I provide a drawing? How much discussion should go into mass and units? Should I even bring these concepts up?

In the above excerpt, Anne was struggling with the dilemma of how much she should help her students. She was not sure whether to help them set up the equipment or to let them figure it out on their own.

I struggled with this same quandary when I first started teaching science as inquiry. I was continuously trying to decide what assistance should be given to students that are not experienced at inquiry-based learning. As teachers, I believe that most of us want to help our students and it is difficult to have the patience to let them figure out the concepts through investigations. Sometimes it seems less painful to just give them the answers.

Subsequent to the first day, the participants were asked to write an overall reflection about their experience with inquiry modules. The following is Anne's reflection:

> No introduction was made for the material. We simply dove right in. The lab is written sequentially. It mirrors the steps one would make during a natural discovery process. What most influenced my learning was making the discoveries myself.

This was powerful in that the participants themselves were driving the learning process. Furthermore, they were employing the same processes that scientists engage in to discover scientific concepts as Schwab (1960, 1960/1978b, 1962, 1966) advocated. Anne maintains:

> The manipulatives (i.e. the balance itself and the wide variety of everyday objects) were very helpful in developing a sense of equivalency among the objects. For instance, 12 tongue depressors are equal to the mass of 1 nut. The section on converting the masses between items is especially helpful. I can use this lab to teach unit conversions, and it will also illustrate why using units is so vital. Visually, the balance itself is a powerful tool. Actually seeing the lever move to horizontal drives some of the notion of balance.

This was part of the inquiry process that several participants remarked on because several of them planned to utilize the unit on developing an operational definition for mass and balance with their students. What follows next is Anne's part of the reflection where she begins to build on her ideas of inquiry-based learning:

> Inquiry-based learning was definitely part of the lesson. Paige and Perri observed and were on hand to make suggestions and ask questions, but they did <u>NOT tell</u>. They <u>guided</u>. We, the students, drove the learning and the process. WE asked questions of ourselves and each other. Not the instructors.
>
> - we made predictions and tested them
> - we activated prior knowledge
> - we inferred and deduced.

Anne experienced how it was different to be a facilitator rather than a disseminator of knowledge.

During the second day of the class, the participants continued working with mass and balance and came up with an equation that would explain how the seesaw balanced. They also worked with operational definitions and experimented with mass, volume, and density. Anne wrote a note to herself to try and differentiate between circular and operational definitions. When asked, after the second day, to explain the elements of inquiry based instruction, Anne's ideas about inquiry showed more depth since the interview prior to the class. She began to re-story her ideas about inquiry:

> To inquire means to ask questions. As a teaching method, it does not necessarily mean having the students ask the teacher questions. It's a circular process. The teacher poses a question or problem and the students question their own knowledge and experiences as well as each other to arrive at the answer. The teacher's role should not be delivery. His/her role should be as a coach or

> facilitator, as a guide, insuring that the students are on the right track and helping them make adjustments in their thinking if it appears that they are following a misconception. In this broad description, inquiry can be used in any subject.

In the above reflection, Anne adds to her understanding of inquiry-based learning in that she realized questioning is an important component of inquiry even though at this point she was of the opinion that the teacher presents the questions. She was also aware of the importance that students take into account prior knowledge and experiences and question each other. Effective teachers understand that students bring their prior experiences with them to utilize as a foundation from which to build new understandings (Driver, 1994; Duckworth, 1987). What follows is Anne's account of differentiating between hands-on learning and inquiry:

> Combined with hands-on, or laboratory, science, however, it [inquiry] can become a powerful tool for discovery. Not only can the student activate prior knowledge and their partners' experiences, they can actually test their ideas. Immediate feedback in the form of a tactile, visual experience can cement cognitive development at its most fundamental level.

Anne realized that inquiry can be utilized in any subject area but can be more powerful in science when combined with hands-on learning since students could actually test their ideas and try out new ideas with tools. As mentioned earlier, there is a direct correlation between conceptual development and hands-on experiences (Carter, et al., 1999; Driver, 1994).

When I read Anne's reflection, I realized that I concurrently was conducting a personal inquiry as to what will have the greatest impact on the teachers in the course

(Anne and Stacy included). The phrase, inquiry into inquiry (Schwab, 1962), began to take on a new meaning as the full implication of my study began to come into focus. I realized that I was conducting two nested inquiries: one had to do with the physics inquiry course while the other was studying my own teaching practice and methods.

That evening, participants were asked again "what is inquiry?" They were assigned to read a chapter in the book, *Inquire Within* (Llewellyn, 2002) while reflecting on the past two days experience in the course. Anne's interpretation of inquiry continued to deepen in that class might begin with a discrepant event which would pique the curiosity of the students. She resonated with this in that she started out her first day of class by doing just this – starting the new year with a discrepant event:

> Inquiry is an approach to learning that involves a process or exploring of the world, asking questions, making discoveries, and testing those discoveries – driven by curiosity. It begins with noticing something new or surprising.
> The next step is observing, questioning, predicting, testing – making meaning requires reflection comparison, and application.

In the above reflection, Anne continues to re-story her understanding of inquiry-based learning in that she adds to her conception of inquiry. She includes making discoveries and testing them as well as some next steps that students may make.

Anne continued and made a list of what stood out to her as she read the chapter.

1. Hands-on recipe science is not inquiry – it's linear.
2. Doing inquiry does not lead to understanding inquiry.
3. Inquiry is not the same as using the scientific method.
4. Inquiry does not have to be chaotic.

5. Asking questions is not inquiry.
6. I need to make time for inquiry.
7. I've found my own beliefs and practices about learning and teaching challenged by what I've learned in this class. Acting on my new perspective will likely change my teaching habits.

Anne realized that it will be a big challenge to change the way she teaches which she still continues to struggle with to this day which illuminates the theory to practice divide in that intellectually knowing something and humanly bringing it into one's own practice and pedagogical actions are not the same things (Schwab, 1983). After all, it is difficult to make time for inquiry with all of the pressure of sticking to a district scope and sequence. This pressure is actually intensified during the second semester because of some death threats and bomb threats that targeted students in her school. The pressure to move on and cover monumental amounts of material is something that most teachers face.

This brings me back to my physics teaching days when all of the teachers teaching physics would plan together in their professional learning communities. I was part of a team of three teachers teaching academic physics. The other teachers were displeased because I would typically lag behind them in the scope and sequence during the first part of the semester. They finally learned to ignore what I was doing and move on without me as they learned that I would catch up to them by the end of the semester. I was able to progress through the scope and sequence at a faster rate as I would not have to re-teach concepts learned earlier in the year.

Prior to the next day of class, the class had a discussion about inquiry and constructivism initiated by the instructors. Anne's conception of inquiry continued to evolve as she wrote in her journal about constructivism:

> A child's body of knowledge can be compared to a stack of books, an irregularly-shaped object, or a pool of various depths. The solid, for instance can change shape, volume, even color as the child's experiences evolve. Children build simple, concrete notions based on their experiences and peer interactions.

Anne's response reminded me of my own reflection of the students in my classroom where I wrote the following in 2005 after participating in a class whereby physics was taught as inquiry:

> In my classroom exists a kaleidoscope of colors; each student represents a different shade, some which are similar but none that are identical. Each shade symbolizes the uniqueness that each student possesses through both educational and life experiences. Moreover, each student comes to the classroom with his or her own canvas, not one of which is blank. Some students may have one color on their canvases, while others may come to the classroom with several shades that demonstrate the depth in the foundations of their own pictures.

We both realized that each student was different and brought different experiences with them to the classroom.

Anne continues:

> Constructivism starts with what a child knows and scaffolds with a concrete engager that challenges and prompts questions. When they learning through inquiry, an engager will either perfectly reflect some aspect of that conceptual

> solid or will more likely challenge it. This causes a disequilibrium that forces the student either to discard the observations or fit them into a new knowledge. A conceptual change model: a belief is part of one's reality – molded through experiences.

The above passage/text shows that Anne realized that student misconceptions are powerful and must be addressed for further learning to occur. Next, Anne continued with how conceptual change can be brought about when students confront misconceptions and form new structures:

> A change results in accommodations in the concept when the new model appears to fit their observations better than the old one. When this occurs, a new concept emerges. A child uses her senses to observe the world and make inferences. Inferences lead to theories and knowledge. A sponge, on the other hand is passive and does not test and revise or continuously observe.

Like Anne's reflection above, I also realized that student misconceptions are powerful and difficult to change. I continue with my own journal reflection from 2005:

> Addressing student misconceptions is an essential component of the lesson. If misconceptions remain unaddressed, further learning stagnates. Some misconceptions must be painted over, and others must be slightly altered. Through facilitating rich discussions with the students, teachers can ascertain the prior misconceptions concerning a concept that students may possess.

Similar to Anne, I too came to realize that students hold onto their misconceptions unless they form new mental models based on experiences which may be through experimentation. Research supports that teachers need to work with students' misconceptions (Bransford et al., 1999). Also, each misconception may be held onto by each student at a different depth. Below, I realized that each student, class, and lesson required unique responses:

> Additionally, students' questions serve as valuable information which the teacher can scrutinize to inform instruction. Each lesson and each student may require a different paint brush in order to facilitate learning. Some students may require fine strokes to sharpen the focus of their ideas while others may invite broad strokes to develop the underlying idea; however, the richest landscapes emerge when students and teachers paint simultaneously.

I believe we were both struggling with the intricacies and complexity of enacting inquiry-based learning into our own classrooms after having been a student of inquiry in a graduate level class. The process of how children learn is complex in that they all bring different experiences and levels of education to the classroom, which are addressed by the teacher in the moment of teaching. As Schwab (1983) stated: "There are a thousand ingenious ways in which commands on what and how to teach can, will, and must be modified or circumvented in the actual moments of teaching" (p. 245). Moving forward to today, I am still experiencing this difficulty as each teacher with whom I work brings a different set of experiences to the class.

Anne's Plan for her Class

As Anne became more excited about how she was learning the physics content, she saw great potential for her own classes that she teaches and began to make a plan of how she could implement inquiry-based learning into her own classroom. She realized that this will most likely be new to her students and that she must scaffold this process to minimize the frustration. She made the following notes in her journal:

> Beginning of school year: establish classroom culture, procedures. Start with demos and discrepant events to encourage observation. Go to activities (make them less cookbook style with time) then more to teacher-led inquiry and finally student inquiry.

In the above, Anne realized that it is imperative to first engage her students in the lesson and she decided to start her lesson with exciting demonstrations. Also, she learned that she could also uncover student misconceptions by showing discrepant events. In the following, Anne comes up with ways in which to adapt some of her more traditional activities into inquiry-based activities:

> How to adapt an activity:
>
> 1. Add an investigation/question – encourage kids to ask "what if".
> 2. Remove predetermined data tables.
> 3. Remove procedure.
> 4. Remove starter question – instead do a demo and encourage kids to ask questions to investigate.

Anne highlighted some potential problems she could have with her class while transitioning to a more student-centered teaching model in this next journal excerpt:

> Statements that may apply to me:
>
> - The classroom gets out of control.
> - I need to prepare kids for TAKS.
> - My students want the answer, not questions.

- Inquiry is too slow.
- My kids cannot do inquiry.

Anne enumerated possible solutions to the above potential problems that could transpire with her class:

- To reduce chaos, I need to establish guidelines for group work that demand responsibilities from my students.
- I can incorporate TAKS facts into lessons.
- My students will gradually adjust to thinking in terms of questions other than answers.
- Inquiry can be continuous and incorporate several concepts at once.
- They can do inquiry if it's introduced gradually.

On the last day of the class, the participants were asked to write in their journals about their final thoughts regarding the entire experience. Anne explained:

> I have never studied a topic the way I've approached physics through inquiry. To some extent I felt as if it was "sink or swim", but the questions and answer technique helped me gain a deeper understanding of the material. I'm accustomed to learning via lecture and independent practice. I teach my students the same way.

As Schwab (1962) explained, inquiring classrooms require skills that are not common in our schools. They require the transformation of a traditional classroom to an inquiring classroom. This necessitates new skills and habits. As Schwab maintained, currently, our teaching laboratories incite students to verify existing knowledge instead of uncovering unsolved problems. Even when students are engaged in problem solving, they typically apply a set procedure to a new situation; the students are not invited to solve problems for which a solution does not exist (p. 39). Hence, our students' creativity is squelched and they do not learn science the way that scientists conduct their research as mentioned earlier. Readers will recall that Schwab (1060/1978b) advocated that students should work in the laboratory prior to the teacher introducing formal scientific principals and concepts. In short, science should be taught as inquiry. In the following, Anne formulated a plan to teach science as inquiry in her classroom:

> Now I have to wonder if this method [lecture] results in true understanding. The obvious conclusion is that it doesn't. Looking ahead, I feel energized about how I'm going to apply inquiry in my classroom. It will have to be a gradual process, but my students, once they feel confident working together and knowing that mistakes are part of the process, will likely embrace the process and ultimately become better thinkers.

Additionally, Anne took a post course survey which consisted of the same questions as the pre course survey and she answered them differently. The theory-practice split is no longer evident and she added another dimension to her formation of inquiry-based learning. Instead of the teacher asking questions, she believes the students should form their own questions. Anne's responses to the post-course survey are depicted in Figure 6.

Post-Course Survey: Anne's Responses	
Question	What do you consider to be the key elements of inquiry-based instruction? In other words, how would you recognize inquiry-based teaching in a secondary science classroom?
Answer	Prompting the students to pose their own questions. The teacher acts as a coach or facilitator. The students are introduced to a topic by referencing their experiences and knowledge – they learn in peer groups.
Question	Do you agree with the following statement? In theory, inquiry-based instruction represents best practices in secondary science instruction; all instruction should be done in this format.
Answer	Yes – I agree. It is important to remember that lectures and direct instruction have their place and cannot be completely abandoned.
Question	Do you agree with this statement? In practice, inquiry-based instruction represents best practices in secondary science instruction; all instruction should be done in this format.
Answer	I agree. Most students have not been taught through inquiry and so must be gradually eased into the process.
Question	Briefly describe how you plan to implement inquiry-based learning next semester (if at all). Please include the source for any curriculum materials you will be using.
Answer	I will try to begin each new unit with a demo that captures the students' attention and prompts them to ask questions. I will gradually phase-in student-led investigations by modifying my "recipe" labs.
Question	What do you see as possible barriers to implementing inquiry-based learning into your classroom?
Answer	Classroom discipline – it will get loud. My administrator may not see learning – he may just see chaos.

Figure 6. Anne's responses to the post-course survey.

Anne's Plan Becomes Lived

A few months after her new semester began, I emailed Anne to ask if the summer course had impacted her practice. This is her response to me in which she re-stories her barriers and unveils another hindrance, herself:

> I have definitely used more inquiry lessons this year. As always, my biggest obstacle is myself. I have taught science for six years and had developed a model of instruction that relied on talk, do, talk. And then some more talk. And then lots of paper.

Readers will recall from the review of literature that it is difficult to undo several years of learning in a lecture type format and that the first step is for teachers to change their learning history (Windschitl, 2002). Nevertheless, Anne follows through with her plan that she put in place over the summer:

> My planning model now begins with some kind of engager followed by questioning. My students love the action oriented pace of the class, and though they are still very fluent in helplessness, as a group we are evolving (in fits and starts) to self-reliance.

Learning a new style of teaching for the teacher and learning for the learner causes both the teacher and student to take on new roles which is an art. Schwab (1962) stated, "This kind of skill is learned by doing, by exercise, and is taught by guiding the doing" (p. 67). Guiding students has been a challenge to Anne which she indicates in the following:

> Learning how to guide rather than simply give has been my greatest challenge, and I will always struggle with that balance. The professional development has absolutely changed my teaching, and I do see a deeper understanding among my students.

In another email she shares some problems with enacting inquiry as she is trying to find the right balance for her classes:

> I've encountered this problem many times as I've tried to teach science as inquiry. Too few instructions and my students give up. Too many, and they refuse to read the whole page! I'm trying to find that balance for students who are accustomed to being spoon fed. Independent thinking is still the goal.

The above reflection paralleled with a similar experience that I encountered when first employing inquiry into my classroom in that my students were totally frustrated in that they had to devise their own procedure for a lab. They were so upset that they brought this issue to other teachers in the building as well as the principal. Luckily, I was supported throughout this ordeal even though I was new to the school at that point in time.

At a professional development in November, Anne wrote a reflection in which she described how she set out to change her class and also her difficulties with teaching inquiry-based lessons:

> When I introduce chemical reactions, I normally give 2 - 3 days of notes that exhaustingly cover the topics. We next do a lab that shows the reaction of vinegar and baking soda. This year I introduced the topic with a demo: I made "green fire". It's a showy demo that generated lots of excitement and questions. I turned those questions around and posed them to my students. So far, my students have taken formal notes only three times this year.

Next, Anne reflected on the difficulties that she had teaching science as inquiry in her classroom:

> Giving up control was the most difficult thing I've had to overcome. I've had to rely more on questioning and activating prior knowledge. I'm slowly becoming more comfortable with this approach.

As Piaget (1973) conveyed, teachers should guide students instead of lecturing to them. As Schon (1987) asserted, people cannot be taught, but they can be coached; teachers cannot learn for their students; students learn by doing. Coaches help their athletes do something and in this sense, teaching is more like coaching. Teachers help their students to discover and form mental models of physics concepts by providing inquiry activities with scintillating discussion that support intended learning. Anne is continuing to work on facilitating learning instead of disseminating knowledge and has changed her approach as a result of her experience in the inquiry course. Anne reflected on her experience:

> The entire physical science sequence of labs absolutely changed my perspective. Seeing and doing inquiry-based science has made me much more confident.

In an interview, I asked Anne to reflect back on her experience over the summer after teaching one semester. I asked her what affect, if any, the summer course had on her teaching practice.

> Paige: What affect, if any, did the summer class have on your teaching practice?
>
> Anne: I have really grown into the teaching profession and feel more confident. I do not rely on the lecture model any more. I have less paperwork (worksheets and notes). My questioning has developed and I have worked on my wait time. I sometimes struggle with this because I know the

answer and want my students to know the answers as well. I can usually guide them by continuing to ask probing questions.

Paige: Is the administration supportive of your endeavors?

Anne: Generally the administration is supportive of me in that they have paid for CAST twice and let me participate in several professional developments. There are only about three teachers out of nine who strive to improve themselves.

Paige: What did you learn most from the physics inquiry course?

Anne: I now understand this content on a new level. Also, I was able to use the style of learning. I liked it because I was doing the work and learning instead of listening to people talk. I was able to make my own connections. I have really improved in using questioning techniques.

Paige: Are you facing any obstacles to facilitating inquiry-based learning in your classroom?

Anne: My students are used to being spoon fed – "just tell me the answer". I can also be a barrier because I want to tell them the answer even though I do not. It is a struggle not to tell them the answer. Sometimes I end up telling them the answer because I believe that I may have messed up in the process. Another difficulty is getting all of the kids in the group to work in the group. Also, I believe my first few classes of the day are short changed because I get better as the day goes on.

The conversation continued:

Paige: I believe that all teachers feel that way! I remember feeling the same way! How do you feel about the curriculum and TAKS?

Anne: The curriculum is too wide! Do they really need to know all of that? TAKS creates a lot of pressure because it is difficult to cover three years of material on a test. It asks a lot from the kids. The legislature should spend time in the classroom to understand all that impacts kids. One student had a brother who was killed in a car crash and missed school for an entire week. Another teacher had two students whose mother tried to smother them and went to school after that happened.

Paige: What do you believe students are responsible for in your classroom?

Anne: It is the responsibility of the students to have an open mind, study and suspend misconceptions. They also need to have the willingness to question the teacher. My students learn best through hands-on learning. They want to do it themselves and really enjoy science.

It was evident when observing Anne's classroom that her students do benefit from her class. They enter her classroom with a smile and they truly enjoy answering her questions. She shared with me that her most important job is to make her students like what they are doing. She said that we, as agents of the system, destroy imagination by school and learning facts. This remark took me back to 2005 when I remembered learning about the history of the American curriculum in which I reflected that the system wants to turn our youth into robots. As Kliebard (2004) contends, "The general idea of shaping individuals through a system of schooling is at least as ancient as Plato" (p. 80). Our educational system seems to be stuck in the factory model where efficiency was paramount to the success of the system which is diametrically opposed to inquiry teaching where the student drives the learning. This causes Anne conflict because it is difficult to find a balance between student driven inquiry-based learning and covering all of the required objectives required by her school adopted curriculum which necessitates teacher driven lessons.

The spring semester brought some new challenges in that her district was subjected to death threats and bomb threats which seriously decreased attendance for about two weeks. On one day, her school had less than 100 students out of 840 present. As a result, Anne is faced with trying to teach an already packed curriculum with two weeks less, benchmark testing, and the preparation for the TAKS test. Although she is faced with these barriers, Anne's commitment to a great education for her students was visible on a recent classroom visit as her students were participating in a chemical weathering lab. Her first approach was to have the students make up their own procedure for the lab. However, this was taking too long and she eventually gave them the procedure. Still, her students were very engaged in the lab and even thought up some additional questions that they could test if they had time.

Stacy's Journey

Background

Stacy began her journey to become a teacher in college. As a salutatorian in high school, she was able to attend a very prestigious college in the state of Texas. At first, she majored in engineering but then quickly realized that engineering was not for her. Although she mastered all of her high school math and science classes, she believed that they did not adequately prepare her for the rigors of an engineering program. Stacy explained, "I remember correcting my chemistry teacher in high school. I really was not challenged cognitively in high school. Most of my classes consisted of memorization and I was successful by studying and working hard. I was a perfectionist." According to Stacy's mom, the district had to adjust to their clientele and as a result, did not have high expectations for their students. They had to teach to the masses. Readers will recall that students of rural and high poverty schools have less access to expert teachers, high quality curriculum, and good educational materials. Many rural schools do not have enough higher level courses to develop the talents of their academically gifted students. Moreover, students in rural schools typically have lower expectations by their teachers and parents (Darling-Hammond, 2010).

After receiving a scholarship, Stacy majored in agricultural education with the hopes of becoming an agricultural teacher. In her youth, she was involved in 4H and her dad was a farmer; her mom was a teacher so the teaching world was not foreign to her. Her teacher preparation was traditional in that she completed four education courses where she developed lesson plans. Her major experience consisted of student teaching which took place in a school far away from her home town. Stacy clarified:

> My school took a lot of time to match the student teachers in a place where we would have the most growth. Although I was not happy with the placement at the time, looking back it was a great placement for me in that I was able to work with three different agricultural teachers who had three different styles.

After student teaching, Stacy moved back to her home district where she applied for a teaching job; however, there was not an agricultural teaching job open. As a result, she accepted a job as a long term substitute for math. Shortly thereafter, Stacy accepted a job as a 7th grade science teacher where she taught for a few years before being moved to an eighth grade science teaching position. She shed light on this new teaching assignment:

> I was moved to the eighth grade without being asked. My administrator was not happy with the eighth grade TAKS scores and felt that I was doing a great job teaching seventh grade and decided to move me without any input.

This proved to be a fruitful move for the district as their 8th grade TAKS scores increased 10 percent the first year and three percent the next year. However, I wonder why they did not get Stacy's input on changing teaching assignments. At the same time, Stacy immediately began her masters in administration and completed her degree in 2007. Depending on which day you ask her – she may or may not want to be in administration as she prefers the curriculum side of administration as opposed to the mundane side of behavior.

Stacy decided to embark on the physics inquiry course because she is continuously seeking ways to improve her craft. Her image of a good teacher prior to the course was a teacher that possessed high expectations and explained things so well that students would remember it. Stacy reflected on her experience as a student:

> Thinking back to my experience as a student, most of my experience was of the "stand and deliver" variety. I could do math all day but not understand it. As a teacher I came to the realization at some point "stand and deliver" will not work and that you actually need to understand the material. I believe that some memorization is necessary but should not be the entire focus of learning.

As per McDermott et al. (2000), students need to engage in concrete experiences to help them develop an understanding of scientific concepts. It is not surprising that Stacy did not have a good understanding of the math concepts because she learned procedurally instead of conceptually. As Ma (1999) contends, many mathematics teachers in the United States understand mathematical topics procedurally instead of conceptually and thus teach their students the same procedural understanding.

In her own practice, Stacy is reflective in that she is always seeking ways to figure out what works with her students:

> I want my students to be successful and make it work. After each lesson, I reflect on what worked, what did not work, and what can I change? I am always getting involved in professional development and seeking new ways to improve myself as a teacher.

Stacy's Journey with the Physics Inquiry Course

Stacy's answers to the survey were similar to Anne's in that she also believed in inquiry-based learning in theory but not in practice. What follows is an excerpt from the survey:

Pre-Course Survey: Stacy's Responses	
Question	What do you consider to be the key elements of inquiry-based instruction? In other words, how would you recognize inquiry-based teaching in a secondary science classroom?
Answer	Students would be working hands-on to discover a concept/solution.
Question	Do you agree with the following statement? In theory, inquiry-based instruction represents best practices in secondary science instruction; all instruction should be done in this format.
Answer	Yes – I agree.
Question	Do you agree with this statement? In practice, inquiry-based instruction represents best practices in secondary science instruction; all instruction should be done in this format.
Answer	No.
Question	Briefly describe how you plan to implement inquiry-based learning next semester (if at all). Please include the source for any curriculum materials you will be using.
Answer	I am not sure how I plan to implement this into my own class. I'll know more after taking this course.
Question	What do you see as possible barriers to implementing inquiry-based learning into your classroom?
Answer	I'm not sure.

Figure 7. Stacy's responses to the pre-course survey.

After completing the first day of the course, Stacy reflected in her journal:

The hands-on measuring activity is great for problem solving and critical thinking. I do not do enough problem solving with my students. Over the last five years of teaching, I have struggled with following a model of teaching that wants the students to inquire/explore first. Today's lesson was very powerful from a student and teacher perspective.

From Stacy's reflection above, she believed that the students should explore first but did not necessarily know how to translate this into practice. Her experience as a student in exploring before explaining helped her to come up with a teaching model in which the exploration occurred first. Next, Stacy delved into her own misconceptions as a learner:

> I saw misconceptions students may have with simpler concepts because I personally experience the misconceptions. From a teacher's perspective, Paige modeled great questioning that helped guide us in the learning process.

As readers will recall from the review of literature, teachers possess many misconceptions that they pass down to their students (Ineke et al., 1999). Because Stacy was able to confront her misconceptions and work through them, she changed her conceptual understanding of the physics concepts. Additionally, having multiple representations to learn concepts was valuable in her learning experience:

> We used an arm with a fulcrum, a see-saw, mathematical equations, and visuals to represent balancing. The arm with a fulcrum acted like a balance where the mass and distance/location of the object could be manipulated. The seesaw had a cylinder for a fulcrum (held by clay) and a meter stick for the arms. Objects were then placed on each side of the fulcrum until balanced. The two items described above helped us to create mathematical equations about balance and mass. $M_1 + L_1 = M_2 + L_2$. Last, we used visuals like different sized blocks to show equal measure.

It is later evident that utilizing multiple representations was powerful for Stacy in that she used this technique in her own class. Furthermore, multiple representations are an essential tool to help students learn and understand physics concepts and also help students to act and think like scientists (Dufresne, Gerace & Leonare, 1997).

In the next part of her journal, Stacy began to re-story her ideas about inquiry. She continued in her journal:

> Inquiry-based learning was utilized today because each of us had to inquire/explore each concept that was introduced. We questioned each other, predicted, and tested our ideas until we came to a conclusion. As we went further in the lesson, we realized some of our previous conclusions were wrong or flawed causing us to develop improved conclusions until we saw the big picture.
>
> This took me back to my own experience when I learned about all of the misconceptions that I had with circuits. It was embarrassing that I was teaching a high school physics class simple circuits and harbored many misconceptions that I passed along to my students.

In a later reflection, Stacy reflected on the difference between inquiry-based learning and hands-on learning:

> Inquiry-based learning is student-based. Students confront their own misconceptions and work through them. They develop a deeper understanding of the concepts. Hands-on learning gives students the information and asks them to manipulate to derive an answer. Students do not get to work through their ideas or misconceptions.

This was a powerful reflection in that many teachers believe they are teaching inquiry-based learning if their students are doing “hands-on” activities. This reminded me once again of the Ma (1999) book in which many mathematics teachers would use manipulatives but would not have the students engage in meaningful discussion with their peers or their instructor subsequent to their experiences. As Ma explained, “In contrast to the U.S. teachers, the Chinese teachers said they would have a class discussion following the use of manipulatives in which students would report, display, explain, and argue for their solutions” (p. 26). After a few more days, Stacy wrote the following about the course:

> I love making connections between math and science. We don’t always make those connections for students. Some would have a better understanding of science if they knew where it came from and that someone didn’t make it up. Inquiry was present when we made predictions about temperature (engage), tested those ideas (explore), gave explanation for our finding (explain) and developed understanding.

I believe Stacy was experiencing the power of driving the learning process herself. She was engaged in discovering physics concepts as a scientist would. Moreover, she reflected again on engaging in the learning process (exploration) prior to the explanation. Stacy continued her reflection:

> Inquiry based learning leaves a larger impact on students. Inquiry based learning is being pushed because of the impact on student learning through problem-solving and critical thinking.

Stacy told me in an interview subsequent to the course that she is a visual learner. This took me back to her journal in which she made a concept map of inquiry early in the course and then later on in the course. The next figure depicts her conception of inquiry early on in the course:

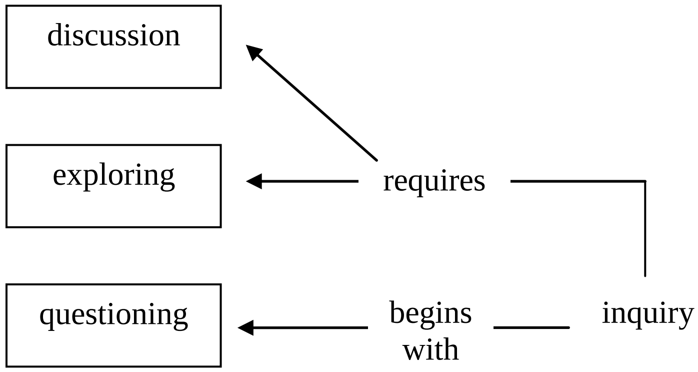

Figure 8. Stacy's initial visual depiction of inquiry.

Toward the end of the course, Stacy re-drew her visual depiction of inquiry. It is evident that her ideas of inquiry advanced tremendously in that Stacy showed more depth in her understanding of inquiry and made more connections between important components one might see while facilitating inquiry-based activities. Figure 9 shows Stacy's new concept map of inquiry:

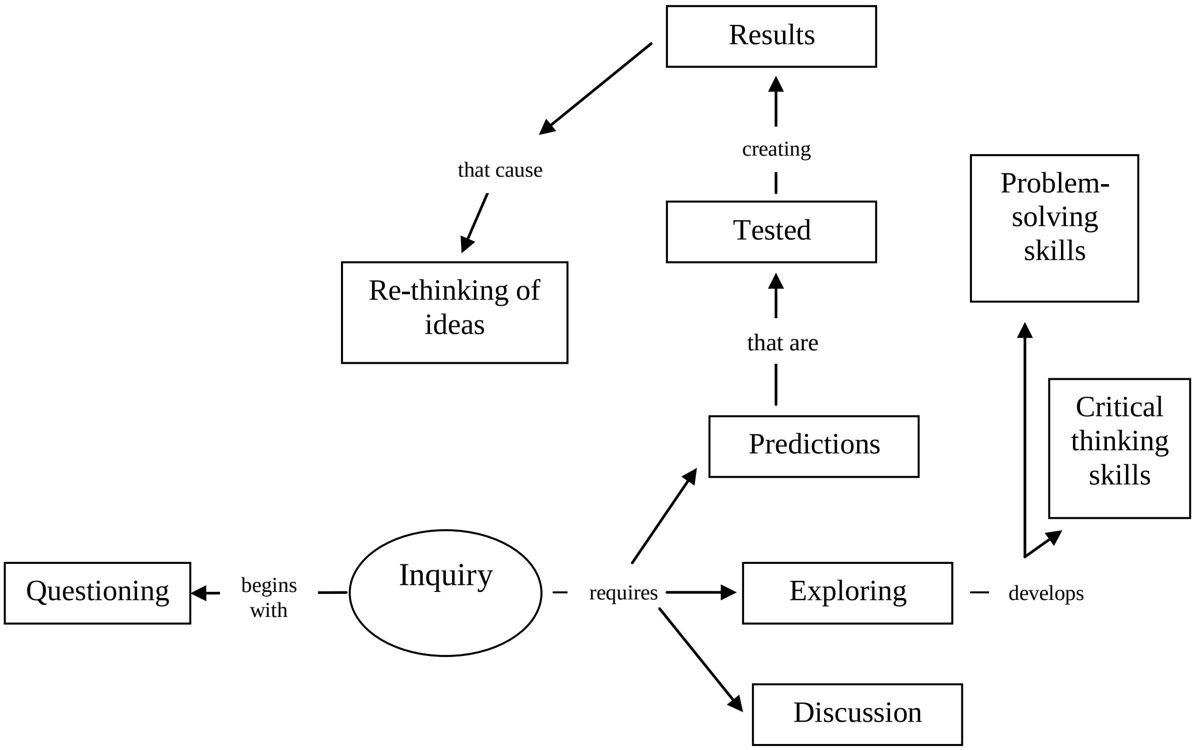

Figure 9. Stacy's new concept map of inquiry.

Stacy's diagramming reminded me of the literature on how concept maps differ in novice and experts and that a novice may have more of a linear relationship whereas an expert typically portrays many connections between ideas and concepts (Bransford et al., 1999). It was evident by these visual representations that Stacy's conception of inquiry-based learning was deepening and growing in complexity.

Stacy's Plan for her Class

Stacy formulated a plan to facilitate more inquiry-based learning and less direct teaching. Additionally, she began to discuss some barriers in her journal:

> The amount of direct instruction should be less often than inquiry based instruction. The exact amount would depend on the students I am presently

> teaching. In fact, it will also depend on each individual class as they all have different needs and ability levels.

Readers will remember that curriculum makers tailor the lived curriculum to meet the needs of their present students (Craig, 2010). Stacy was devising her plan from a curriculum maker's point of view. She continued to formulate her future plans:

> Inquiry based instruction would be a majority of how I deliver instruction. It will take time to get students who are not automatically curious to start asking questions. I would begin with teacher-led inquiry. As students start to ask questions about procedures/directions, I will begin to ask questions of them pushing them to think through the steps and to make a decision.

Stacy was referring to the inquiry continuum (National Research Council, 2000) in that she plans to take the essential features of inquiry shown in Table 1 and transform her class from one that has more direction from the teacher or material to one that has less direction from the teacher or material. Stacy described below her strategy to gradually transition to a class with more learner self-direction:

> As time passes, I will move toward student-centered inquiry. As a child reaches student led inquiry, they are critically thinking and learning to develop their own understanding of a concept. They begin to question (scientific skepticism) and inquiry about the things around them.

This reminded me of my own experiences in teaching physics when I first started facilitating inquiry-based learning subsequent to the physics inquiry course I took in my master's program in that some of my classes were more resistant to this type of learning than others. My students became very frustrated with the entire process. I did not have a great plan of how to change my class over to inquiry-based learning. Instead, I proceeded to change my style of teaching starting with the new school year. I now wonder if it is better to throw your students into the process or to gradually evolve to an inquiry-based class. Below, Stacy discussed some barriers:

> I realize that it will take a significant amount of time to plan for inquiry.
>
> I will have to teach or guide my students to become inquiry type thinkers. It will take time to change their way of thinking and learning and I'll have to push them at times.

When I read the above in Stacy's journal, I thought the time barrier she was referring to was the time it took to write inquiry-based lessons. In a future conversation, I realized that she was talking about the time necessary to enact inquiry-based lessons.

> I will have to work at becoming more efficient at developing/restructuring my lessons to fit inquiry. Actually, I think it will take more time to change my teaching mind to inquiry based as I am used to more direct instruction and running my classroom more traditionally.

In the above reflection, Stacy realized that she is a significant barrier in this entire process since she has grown up in a traditional system and spent several years teaching with this mindset.

As a requirement for the course, the teachers took an existing lesson and transformed it to an inquiry-based lesson. Looking back on the reflections of many, I realize that it would have been more beneficial if we did this assignment during the course instead of making this an outside assignment. When do teachers have enough experience in inquiry-based learning to rewrite their lesson plans? Stacy explained her thoughts regarding lesson planning:

> I find it difficult to move a lesson toward student-centered learning. It takes careful planning and great questioning. Again, it is finding a way to overcome barriers to inquiry based teaching like your own mindset and administration.

At the end of the course, Stacy took the post course survey and had different answers which showed growth in her understanding of inquiry-based learning. What follows is an excerpt of Stacy's responses to the post-course survey in Figure 10.

Post-Course Survey: Stacy's Responses	
Question	What do you consider to be the key elements of inquiry-based instruction? In other words, how would you recognize inquiry-based teaching in a secondary science classroom?
Answer	Students are actively engaged in inquiry-based teaching. Students are asking questions and the teacher is facilitating learning. The classroom is under control and all students are engaged.
Question	Do you agree with the following statement? In theory, inquiry-based instruction represents best practices in secondary science instruction; all instruction should be done in this format.
Answer	Yes – I agree. All is a strong work because not all topics lend themselves to inquiry.
Question	Do you agree with this statement? In practice, inquiry-based instruction represents best practices in secondary science instruction; all instruction should be done in this format.
Answer	I agree.
Question	Briefly describe how you plan to implement inquiry-based learning next semester (if at all). Please include the source for any curriculum materials you will be using.
Answer	A majority of our lessons follow inquiry but my goal will be to change the way I teach/facilitate learning (i.e. using questioning). Also, some lessons could be moved toward total student-centered instead of partial student-teacher.
Question	What do you see as possible barriers to implementing inquiry-based learning into your classroom?
Answer	Time and changing my way of thinking can be barriers. The way you have planned lessons and taught has to be changed to a new way of thinking.

Figure 10. Stacy's responses to the post-course survey.

Stacy's Plan Becomes Lived

I have had the opportunity to have ongoing professional development sessions, email correspondence, interviews, and classroom visits with Stacy to appreciate her journey in her enactment of inquiry-based learning. At a professional development event, Stacy shared in her journal how she altered a lesson to reflect a more inquiry-based approach:

> I changed my physics lesson on speed and motion into an inquiry based research project. Students researched forces and motion to gain a working knowledge of the concepts. Then, they designed a roller coaster that reflected the concepts learned. They tested the roller coaster, collected data, and reported their findings.

I asked her to elaborate on this in a subsequent interview:

> Paige: What has had the greatest impact on your practice from last summer's physics inquiry course?
>
> Stacy: The facilitating of learning instead of preaching. I now use questioning in my classroom instead of giving answers.
>
> Paige: How did the students receive your speed and motion lesson that you changed to reflect a more inquiry-based approach?
>
> Stacy: This was met with resistance from the parents and later on an administrator that wanted me to give into the parents. You see – the parents were not unhappy with the way I was teaching, they were just unhappy that their children were not receiving "A's" for their work. They (the students) had a difficult time translating what they had done on paper. The students found the open-ended format very difficult. It was a learning curve for both the students and me.

Our discussion continued:

> Paige: What did you do about the parents and the administrator?

Stacy: I did not give in to the parents or administrator. I wrote a letter that said basically that you (the administrator) have never visited my room so how could you know what was going on in my class? How could you make a judgment?

Paige: What happened?

Stacy: It seemed to die down after that and I did not hear any more.

Paige: Did you do any more projects? If so, how did they turn out?

Stacy: This learning curve turned out to be a good thing. I did another project where the students had to predict future landscape of continents (forces with plate tectonics). My students started out on a much higher level and rose to the expectations. They were much more detailed and specific.

Paige: What other changes have you made?

Stacy: I am sure to have multiple representations and have TAKS based questions at the end.

During the physics inquiry course, we were always sure to have multiple representations of similar concepts. This brought me back to another reflection in her journal during the physics inquiry course: “We used an arm with a fulcrum, a see-saw, mathematical equations, and visuals to represent balancing.” This was evident in a recent classroom visit where Stacy held a test review in which the students were able to learn about landforms in multiple representations such as a puzzle, an interactive group activity, an animation, and a card sort. The interview continued:

Paige: What are your thoughts on the TAKS test?

Stacy: The science TAKS test is a lot for the kids to remember. They have to remember multiple years which can be difficult since it spans many grades. If we all (all of the teachers) did a better job, maybe it wouldn't be so difficult. All of the teachers need to "buy in" to what is going on.

Paige: Are you facing any barriers to enacting inquiry-based learning?

Stacy: My teaching partner and I had the mindset that the students could not do it. We needed to get out of that mindset and guide their students enough to where they could get the information on their own.

Paige: How did you do that?

Stacy: I eventually wear them out. I do not give in. Finally, the students realize that I am not going to give them the answer and say to the others in the class: "quit asking because she is not going to tell you".

In the above, Stacy re-storied her barriers to reflect that her low expectations of her students were the main barrier that she had to overcome. As Piaget clarified (1973), it is difficult for teachers to let go of being the disseminator of knowledge. I wonder if the physics inquiry learning experience is enough to impact the deeply rooted mindset of many teachers.

In an email at the end of the semester, Stacy responded to my inquiry about her classes. The following is an excerpt from Stacy's reply:

> My students seemed to struggle this semester with inquiry based learning. Maybe it was a learning curve for my students and me. I learned what parts of the lesson lacked direction or where the students needed more instruction/information from me.

The above reflection illustrates the ongoing journey of Stacy and her students during the school year. Stacy takes into account her learners as part of the process which is one of the four commonplaces for curriculum to occur as maintained by Schwab (1960/1978a). Next, Stacy reflected on her own mindset:

> Inquiry-based learning is a process that a teacher has to learn to develop or "be." It can't happen overnight. You have to change the way you've always thought (i.e. give the students the information then have them experiment and practice) or been taught yourself. Secondly, you have to start learning how to ask questions to facilitate the learning.

Readers will recall that questioning is an essential component of inquiry-based learning and is essential to conceptual development (Aarons, 1999). In Stacy's final thoughts, she continued to ponder the necessity of changing her mindset before embarking on inquiry-based learning:

> Inquiry based learning is not as simple as just creating the lesson. It also requires an intrinsic change of the teacher. I'm glad y'all are teaching future teachers how to create inquiry based lessons. Hopefully, your students have any easier time of adapting to that type of teaching.

The above caused me to reflect on my current job in the *teach*HOUSTON program where I serve in a leadership role as a science master teacher. It is a future goal of mine to incorporate a science as inquiry course as part of the sequence of courses that our preservice science teachers undertake in their teacher preparation program. Will this course impact preservice teachers as it has impacted in-service teachers? After collaborating with other master teachers in the *teach*HOUSTON program, I submitted the necessary paperwork to offer this course starting in the fall, 2011 semester. As an instructor of this inquiry course for in-service teachers, I illuminated the experiences of two participants, Anne and Stacy, as they learned physics as inquiry and transformed their own practices. Additionally, I reflected on my own practice as an instructor and previous participant of the physics inquiry course. Potential implications of this study for teaching future inquiry courses and future research emerge in chapter five.

CHAPTER FIVE: DISCUSSION AND IMPLICATIONS

INTRODUCTION

This doctoral thesis research unearthed the experiences of two teacher participants, Anne and Stacy, as they first learned physics as inquiry and subsequently enacted inquiry-based learning in their own science classrooms with the secondary students before them. My research puzzles had to do with the teachers' physics inquiry course, subsequent professional development sessions, and the physics modules that were created. My questions were: Will the physics inquiry course and professional development experiences impact how much physics content is learned? Will learning physics through inquiry impact the attitudes teachers have toward teaching through inquiry? What roadblocks do teachers encounter when trying to enact inquiry lessons? Can teachers better overcome these roadblocks after the inquiry-based physics course and professional development experiences?

In this chapter I lay the story constellations for Anne and Stacy side-by-side to illuminate common themes that emerged through their journeys as learners and teachers, some of which were the same as I experienced as a learner and teacher of the physics inquiry course. Story constellations (Craig, 2004, 2007), a fluid version of narrative inquiry, occurs within a "*three-dimensional narrative inquiry space*" which allows travelling in the following directions: "inward, outward, backward, forward, and situated within the place" (Clandinin & Connelly, 2000, p. 49). I realized that the teachers' work lives unfold in a myriad of "story constellations" (Craig, 2007) and will expand on only one small part of that constellation – their taking the science inquiry course and transforming their course learning on inquiry into lived practice in their science classrooms. Readers will recall that in chapter four I considered both Anne's and Stacy's stories separately using the analytical tools of broadening, burrowing, and restorying. In order to arrive at common understandings for both Anne and Stacy, I arrange their stories side-by-side in this chapter to illuminate the shared themes that emerged throughout their narratives. Next, I probe the meaning of their stories and restory their experiences in addition to my own. Finally, I reflect on the leadership decisions necessary to include this as a course in the *teach*HOUSTON program for preservice teachers and reflect on possible future research.

BACKGROUND OF INQUIRY COURSE

The idea for this study originated in 2005 when I was a student of the Physics by Inquiry course in my master's degree program at the University of Texas in Austin. After personally becoming a student of inquiry, I was able to transform my high school physics courses to reflect an inquiry-based curriculum. Although the transformation of all of my lessons did not occur immediately, I was able to change most of my curriculum over the next three years. This was because I recognized the importance of physics taught as inquiry and desirous of incorporating into my plotline as a learner and a teacher. Of course, curriculum making is ongoing and responsive to changes in students, the influences of teachers alongside you, administrator decisions and suggestions, and discussions with parents. As a result of this experience, I wanted other teachers to have a similar opportunity to the one I encountered in the physics inquiry course. I believe this optimum experience as a learner was the stimulus that, in turn, led to the transformation of my classes. Although I learned about inquiry prior to the physics inquiry course, I truly did not understand inquiry until I was a student of inquiry. To be certain, formal knowledge of inquiry is important to the teaching act; but, it is not the only thing: Teachers need to have personal experiences of inquiry that convince them as individuals of its importance to the teaching and learning of physics. They need to take the learning of physics as inquiry into their personal plotlines as teachers as they actively instruct students who themselves are learning physics.

Some of my colleagues from my master's program transformed their classes to reflect an inquiry-based curriculum but some did not. Some members of the cohort went back to their classrooms and pulled out the folders from their filing cabinets and taught as they had done in previous years without making changes. They were in essence curriculum implementers consonant with the definition of teachers endorsed by government agencies. Some members cited administrative mandates, curriculum, and the TAKS test as the obstacles they could not surmount. While I am not diminishing these barriers to facilitating inquiry-based learning, I wanted to study those who changed their curriculums subsequent to the inquiry course and in spite of those barriers. Several members of the summer 2010 physics inquiry course followed the same pattern as those in my master's cohort. Many decided to change what they were doing in their own classrooms while other participants did not make any changes. I chose to tell the stories of Anne and Stacy because they made changes subsequent to the physics inquiry course and had experiences that paralleled my own. Both Anne and Stacy were curriculum makers; both were both impacted by the TAKS test and a district mandated curriculum, and both were able to confront these barriers to enacting an inquiry-based curriculum that all physics teachers face. Additionally, their experience as students of inquiry helped them to develop a better understanding of inquiry as well as to understand how inquiry can actually work in their classrooms with secondary students.

INQUIRY INTO INQUIRY

The first theme that emerged from both Anne and Stacy was the impact of learning physics concepts as inquiry. Prior to the physics inquiry course, both Anne and Stacy did not believe it was feasible to actually enact inquiry lessons in their own classrooms. Readers will recall that both Anne and Stacy believed inquiry was an appropriate means to teach in theory but not in the real-world of practice with all of its policy prescriptions and human dynamics. Additionally, prior to taking the physics inquiry course, I did not fully grasp the intricacies of hands-on learning verses inquiry-based learning. However, after learning physics as inquiry, I was able to instantiate inquiry-based learning in practice. Both Anne and Stacy reported on the post-survey that they believed teaching science as inquiry represents a best practice in secondary science; they believed their students would learn science concepts at a much deeper level with inquiry-based learning. Readers will recall from an interview that Stacy said that "the facilitating of learning instead of preaching had the greatest impact on her practice from last summer." Anne echoed the important of the inquiry course when she said the following: "The entire physical science sequence of labs absolutely changed my perspective. Seeing and doing inquiry-based science has made me much more confident." Both believed that experiencing the physics lessons as a student was foundational to being able to understand how to breathe life into this practice in the classroom working alongside students.

Prior to the course, Anne and Stacy both believed that there was more to teaching than ‘stand and deliver’ and both believed in the power of utilizing hands-on activities. However, hands-on activities did not always enhance the lesson. Readers will recall that I encountered the same difficulty in my own practice. As a result, I made this the topic of one of the course reflections when I asked all of the participants to differentiate between inquiry-based learning and hands-on learning. Trying to make the differences explicit provoked powerful conversations about instances where the participants felt that there was more to hands-on activities and sometimes the hands-on activities did not always lead to learning scientific concepts. Readers will remember that Anne differentiated between hands-on learning and inquiry in the following excerpt:

> Combined with hands-on, or laboratory, science, however, it can become a powerful tool for discovery. Not only can the student activate prior knowledge and their partners’ experiences, they can actually test their ideas. Immediate feedback in the form of a tactile, visual experience can cement cognitive development at its most fundamental level.

And Stacy also reflected on hands-on vs. inquiry when she said the following:

> Inquiry-based learning is student-based. Students confront their own misconceptions and work through them. They develop a deeper understanding of the concept. Hands-on learning gives students the information and asks them to manipulate to derive an answer. Students do not get to work through their ideas or misconceptions.

In the overall analysis, I asked the participants what had the most impact on their practice from the summer physics inquiry course. Anne offered the following: “What most influenced my learning was the making the discoveries myself.” Also, both Anne and Stacy found the inquiry activities useful in that they could actually employ some of the lessons in their classes. Later in the course, they added that it was actually the model of teaching that was generative in that they could re-enact this inquiry model using several different science concepts and were not limited to those presented in the course. The invitational quality of inquiry was evident in the course in that teachers were invited to engage in inquiry; teachers constructed their own meaning of physics concepts through experiments they devised – we, the instructors, did not dictate how the participants arrived at their conclusions. In short, their inquiry was fluid as there were several potential paths to follow which could also result in different outcomes for the participants.

Throughout the course, both Anne and Stacy developed their concept of inquiry. They started out with an inchoate idea of the concept and were able to form an enhanced mental model after completing the physics modules. In other words, not only were they learning physics concepts through inquiry, they were learning about the enactment of inquiry process itself. Once again, the participants were invited to partake of the inquiry—they were not required to undertake it a specific way. Reflections, readings, and discussions supplemented this learning. This process of learning paralleled my own experiences in my master’s physics inquiry course. Anne reflected prior to the course that the key elements of inquiry-based instruction were presenting a problem to the students and guiding them as they formulated a solution. Stacy’s response to the same question was that students would be working hands-on to discover a concept/solution. Both realized that inquiry was student-driven and were able to supplement their understandings of inquiry as the course unfolded. Readers will recall from chapter four that both Anne and Stacy felt the power of being learners who drove the learning process. They both realized that the teacher serves in the role of a facilitator. Anne and Stacy also experienced the value of making predictions and testing their predictions as well as uncovering misconceptions. Later on in the course, Anne and Stacy reflected that inquiry is not a linear process; Stacy's concept map, for example, evolved from a somewhat lock-step model to one reflecting multiple connections. After teaching the linear scientific method for years, many teachers have the misconception that science is a linear process. Overall, the inquiry into physics and the inquiry into inquiry led to another inquiry – the inquiry into how this can evolve in their own classrooms with all of the inherent barriers embedded in the milieus of their classrooms, schools, and school districts.

CONFRONTING THE BARRIERS

The Teacher as the Barrier

In order to transform their classes to those that were more inquiry-based, Anne and Stacy had to work hard to change their mindsets as to how a class should function. Both were accustomed to being the disseminator of knowledge and this was difficult to change. Readers will recall that Pereira (2005) believes the first step in education reform is to change the way that experienced and prospective teachers learn subject matter (p. 71). This will help teachers not to resort to teaching as they have been taught which in the cases of both Anne and Stacy were largely through lecture. Hence, they both listed themselves as barriers because they tended to direct rather than facilitate. Both Anne and Stacy realized this from the beginning. Anne, for instance, wrote in her journal during the first day of class, "DO NOT help. Make them figure it out." She even used capital letters and underlined to emphasize this to herself. She wanted to break the mold of telling her students what to do and completely arranging the experimental setup for her students as opposed to having her students responsible for the experimental design. In another reflection, Anne noted the following: "Paige and Perri observed and were on hand to make suggestions and ask questions, but they did NOT tell. They guided. We, the students, drove the learning and the process. WE asked questions of ourselves and each other. Not the instructors." Once again, Anne emphasized that she as the learner drove the learning process and the instructor's role should be as a coach, an arrangement which challenged her own beliefs about learning and teaching. When asked after teaching for a semester subsequent to the course, Anne reported that she was a major obstacle because she was used to a different model of instruction. Stacy reported that it will take a long time to change her own mindset and further disclosed that the way she planned lessons and taught had to be adapted to the new way of thinking. Could this be another misconception that must be changed? Earlier, the power that misconceptions have on students was discussed. Perhaps the traditional model of teaching that most of us experienced is also a misconception of teaching that must be addressed. It has become ground in as not just a "best practice," but has become some teachers' only practice. Just as learning physics as inquiry causes students to form mental models of physics concepts, teachers must also form mental models of teaching science concepts differently. Furthermore, when confronted with changing their mental models based on misconceptions, it is very difficult to change misconceptions because they are like root systems of ideas. Stacy, for example, was grappling with how to teach physics – not just the physics concepts themselves. Stacy's difficulties also had to do with time in that she thought it would take more time for her to change her teaching mindset to inquiry-based. She also subscribed to an image of what a proper classroom looked like, which additionally is powerful and difficult to change. Later, Stacy showed that she is inquiring into her own ways of teaching in the following;

> Inquiry based learning is a process that a teacher has to learn to develop or "be." It can't happen overnight. You have to change the way you've always thought (i.e. give the students the information then have them experiment and practice) or been taught yourself. Secondly, you have to start learning how to ask questions to facilitate the learning.

Anne also was inquiring into how to change her class. She reflected on several potential scenarios before coming up with a plan that would work for her class. Reflecting back on the physics inquiry course, I realize that I did not provide any support as to how to live inquiry in practice. I believe more support is needed to help teachers enact inquiry-based lessons in their classrooms and to help them overcome the barriers. I wonder: Does it take the coaching model?

Readers will recall that when an afternoon was spent with Anne – she was able to change the order of her lesson so that the students experienced the exploration before the explanation. However, this takes a large amount of time on the part of the teacher of teachers and there may not be enough human resources to put this in place.

Time as a Barrier

The time barrier evolved throughout the semester following the physics inquiry course. Although both Anne and Stacy brought up time as a barrier during the summer course, this barrier took on heightened meanings throughout the semester. At first, the time barrier referred to the amount of time needed to write inquiry lessons. Then, the time barrier turned into the amount of time needed to enact, breathe life into inquiry-based lessons. I then realized the largest cause of the time barrier was the prescribed curriculum itself. Both districts had implemented district-wide curriculums which originally were supposed to 'fix' everything for everyone in the district. However, both Anne and Stacy were permitted to become curriculum makers instead of curriculum implementers by their administrators. Both Anne and Stacy believe they were allowed to deviate from the prescribed curriculum because both had a background in science and had their students engaged in science laboratories. In short, they garnered the respect of their principals through their teaching and were thus able to create and enact their own science lessons. In spite of this, both still had to follow the district's scope and sequence. Because the curriculum was so dense, it was difficult to have any time at all to teach inquiry lessons since the curriculum covered a wide-range of topics over a short period of time. Anne reiterates this when she says the following: "The curriculum is too wide! Do they [the students] really need to know all of that?" I did not emphasize the research that shows that students who learn through inquiry learn at a much deeper level and therefore, do not have to be re-taught concepts right before the TAKS test. This could be one area of research brought into the next inquiry-based course I teach. Teachers may not have to dedicate the entire spring semester to preparation for the TAKS test if their students truly learn science concepts.

High Stakes Testing as a Barrier

Readers will recall that both Anne and Stacy were moved from their 7th grade teaching positions to 8th grade largely because the students take the TAKS test in the 8th grade. Both Anne and Stacy were respected as teachers and the administration wanted to have the strongest teachers in the grades where this high stakes testing occurred. During the spring semester, this affects the time barrier because much time is taken out for benchmark testing. After benchmark testing, the scores are utilized to pull out certain students to give them further tutorials to help them be successful on the TAKS test. The TAKS test is continuously on their minds as is evidenced from conversations and journal reflections. During a visit in the spring semester, testing was on the forefront of everyone's mind. In the literature, the principal at Eagle referred to this pressure with high stakes testing as the dragon in the school backyard (Craig, 2004): "When you work in a school and there is a dragon in your backyard, you had better prepare for the dragon. The dragon, of course, is the accountability system . . ." (p. 1230). Anne mentioned this in her reflection when she wrote that she needed to prepare kids for TAKS and then later on decided that she would incorporate TAKS facts into her lessons. Can teachers overcome the barriers of high stakes testing? Noll (2010) poses the question: is No Child Left Behind (No Child Left Behind [NCLB], 2003) irretrievably flawed? Ravitch (2010) purports that one of the problems of utilizing standardized exams to make decisions about the lives of students and teachers is that tests are not precise instruments.

In short, crude implements are determining some of the fine-grained contours of students' educations and lives. Likewise, teachers' performances are being judged on the outcomes of these crude instruments. We know that exams ideally should be used in conjunction with other measures such as homework, teacher recommendations, grades within in the class, and class participation. We also know that "scores should be used only for the purpose for which the test was designed: For example, a fifth-grade reading test measures fifth-grade reading skills and cannot reliably serve as a measure of the teacher's skill" (pp. 152-153). The teacher is not in control of learning that occurred prior to that year or what supports or stymies the students' growth at home. Anne referenced this earlier when she said that it was difficult to cover three years of material on a test. Moreover, "student performance may be affected by the weather, the student's state of mind, distractions outside the classroom, or conditions inside the classroom. Tests may also become invalid if too much time is spent preparing students to take them" (p. 153). Many of the teachers with whom I conducted the survey mentioned that their schools close down one month prior to the TAKS test to review for TAKS. During this month, no new learning occurs which makes the task of teaching the curriculum even more difficult. In talking about the pressure of TAKS, Anne stated that the legislature should spend time in classrooms to understand all of the influences that impact student performance. Many educators and administrators are pressured by the intense accountability system that has been instituted and therefore try to boost scores in ways that do not enhance the learning experience. According to Ravitch, "excessive test preparation distorts the very purpose of tests, which is to assess learning and knowledge, not just to produce higher test scores" (p. 160). Moreover, high-stakes testing has a way of narrowing the focus of what gets taught and how it gets taught since the ultimate goal is not to learn physics in a productive way but to perform well on a test. While the students in Texas are impacted negatively by high-stakes testing, there seems to be no end in sight. Curriculum and pedagogy continue to be determined by a test that can have life-changing consequences for students of all ages, which is in direct opposition to the inherent goals of an educator and can have the opposite effect on students' learning.

CHANGES TO THE PHYSICS INQUIRY COURSE

As a methodology, narrative inquiry is a powerful form of investigation because it illuminated the experiences teachers had in learning science as inquiry, inquiring into inquiry, and also brought to light the real barriers faced by teachers who are trying to transform their classrooms into inquiry-based classes. Narrative inquiry is valuable also because it unearthed how large-scale policies can influence individuals in small-grained ways. At the same time, it informed my practice as a professional developer because I have a better understanding of how to work with teachers who are personally trying to transform their classes. I understand the narrative plotlines of teachers' lives and identities more and how critical both are to how teachers teach in classrooms with flesh-and-blood students. Although teaching is fluid in that each class has a different context and different students, similar themes arose in both Anne's and Stacy's classes as they incorporated inquiry-based lessons into their classrooms. Through storying and restorying Anne's and Stacy's experiences, many barriers to enacting inquiry-based lessons were unearthed which will be a topic of discussion in future science inquiry courses. It would benefit participants to discuss the amount of time needed to design and enact inquiry-based lessons with the decreased amount of time given for instruction due to high-stakes testing. Additionally, participants would benefit from discussing how best to change from a teacher-centered lesson to a more student-centered lesson.

The course was successful in that the teachers learned physics concepts through inquiry lessons. This addressed their mindsets concerning what a proper classroom should look like, which was a large achievement. However, changing the mental perception of what a class should look like and enacting this in practice are two different things. More support is needed in lesson writing, practicing, modeling, working with the barriers of time, altering their mindsets, and high stakes testing.

First, more time should have been devoted to writing inquiry lessons plans or changing cookbook lessons into inquiry lessons. Although it was an assignment of the class to do this, feedback was not given to the teachers on their attempts. This was an oversight on our parts. If time permitted, the lessons should have been presented to the entire classroom for feedback and response—so multiple expressions of inquiry teaching could have been entertained. In short, we, as instructors, were intent on having the participants discover physics concepts and neglected to spend enough time unpacking the vehicle for delivery. This was counterproductive. Changing a lesson plan to a more inquiry-based lesson plan is difficult to begin with. Thinking back to my own experience with lesson planning, I was able to work on this transformation in a master's course subsequent to the physics course. I took a course called 'Curriculum and Instruction for Science and Math' where we studied the history of the American curriculum and later worked on writing lesson plans for our classes. The participants would benefit from working in groups of the same grade level to write lesson plans that they could put into action during the school year. The instructors could help with this process which would provide a smoother transition to writing inquiry lessons. By working in same grade-level groups, participants would be building a support network they could utilize during the school year as many of the participants worked in the same school district or neighboring school districts. This would also serve to alleviate the time barrier somewhat because lessons would actually be developed during the summer prior to the teaching.

Trying to decide what is most important to teach during a summer course is an intricate dance. If more time is allocated to working on lessons plans, then less time will be devoted to learning physics as inquiry, which was the original impetus for changing teachers' mindsets. Just as teachers are impacted by curriculum and time, I am as well in that I have a large amount of material to cover in a fixed amount of time. Finding an acceptable balance between working through the physics modules and/or working on lesson plans and discussing their enactment in classrooms is a balancing act, which is an inquiry itself.

As far as the time barrier is concerned, more research should have been presented about the impact of learning science as inquiry. It should have been clarified that many students will not have to be re-taught concepts which will save them time in the long run. Readers will recall that I experienced this first-hand with my physics students subsequent to the physics inquiry course. My students would engage in inquiry activities whereby they would discover the relationships between variables. Although these discoveries initially took longer than directly teaching the concept, I did not have to re-teach the information which resulted in saving time.

Inquiry teaching might be hard to learn due to lack of "rhetoric of conclusions" (Schwab, 1962); however, when you understand how important it is and how flexible it is to use with different concepts and in different settings gives an organic kind of generativity to physics as inquiry and inquiry in general. Inquiry teaching is a generative process because it produces a diversity of responses which can, in turn, be utilized as a resource to structure classroom activity; student responses and actions can give insight into the ways that students are thinking about a task (Stroup, Ares & Hurford, 2004).

Moreover, the challenges teachers face (i.e., time to cover all necessary content; availability of resources; resistance of students; and criticism of colleagues) should have been discussed. According to Michael and Modell (2003), the fears many teachers possess can be lessened by emphasizing that an inquiry learning environment focused on meaningful learning may actually provide an opportunity to cover more content rather than less. As far as covering content is concerned, the authors assert that in passive learning environments, the input state of a student is never assessed; therefore, time may be spent teaching students concepts that they already know. The importance of pre-assessment is emphasized in the book *How People Learn* where the authors emphasize that "teachers must draw out and work with pre-existing understandings that students bring with them" (Bransford et al., 1999). Additionally, the authors stress that teachers can usually modify their materials to be used in an active learning environment; inquiry lessons do not have to be created from scratch. Readers will recall the research mentioned earlier that shows when more time was devoted to concept attainment rather than solving problems, students had the same or higher rate of success in solving problems when compared to students in more "traditional" physics classes (Redish &

Steinberg, 1999). Highlighting this research in the physics inquiry course as well as discussing the participants' personal experience may increase the confidence they have when discussing their lessons with colleagues at their schools. Moreover, misconceptions that students harbor may be thwarted since studies have shown that time utilized in the classroom for hands-on investigations coupled with leading questions and meaningful discussion can eliminate many misconceptions in physics (McDermott & Shaffer, 1992). As a result of deeper conceptual development and addressing the students' misconceptions, teachers may not have to devote entire month or more to prepare for TAKS since much of the material will not have to be re-taught.

As far as the curriculum is concerned, I highly doubt school districts will change their curriculum approaches after spending large sums on district-mandated curriculums. However, regardless of the curriculum document and its restraints, teachers need to take a closer look at the curriculum to decide where to invest more time. Teachers also need to be involved in the curriculum making process. This takes me back to my journal in 2005 where I wrote of the curriculum writing process as a metaphor of a canoe. During that summer, I ran many miles alongside Town Lake where there were always canoeists traveling in various paths. I reflected:

> I visualize the process of instruction and curriculum as being interconnected with each influencing the other. The instruction informs the curriculum; the instruction is dependent on the teacher, students, colleagues, professors, and curriculum makers who are all on a voyage together. The lesson study is the vehicle which transports the participants on a powerful journey; all must be active participants or the course can develop twists and turns.

> In order for a canoe to travel in a straight line, each participant must have equal sized paddles and work to synchronize their movements. If either of these two conditions fails to occur, the canoe will travel in a crooked line and in some instances a circle. As my myopic view of curriculum making transcends above the maze to a birds-eye view, I will be better equipped to help steer the canoe in a straight path; the pathway to student achievement, improved instruction, and an effective curriculum.

In the above reflection, I was pondering the balancing act of being a curriculum maker in a district that was moving in a direction of being more standardized where they wanted all teachers to be alike – to be carbon-copy robots. I committed myself to do what was right for my students – a big battle I was willing to wage. Since leaving the classroom, I fear this movement of standardizing curriculum and confining teachers to the role curriculum implementers has escalated. As part of my role as a science master teacher, I serve as a mentor to graduates of the *teach*HOUSTON program who are in their first or second year of teaching. A large part of their team planning in their schools revolves around ensuring that all of the teachers teaching the same subject utilize the same materials, activities, quizzes, and exams. Furthermore, each team must test and quiz on the same day and instruct the curriculum as decided upon by the team of teachers. While this type of planning was encouraged in the past, it is now an expectation of many administrators. While teaching teams can decide to be a group of curriculum makers, if they give each other permission and space to do so, most of our graduates are not part of a team of curriculum makers. This, too, forms an obstacle. The preparation of a strong, inquiry-minded teacher is a far cry from the cultivation of a group of curriculum makers.

NEXT STEPS

As a science master teacher and leader in the *teach*HOUSTON program, I plan to offer the physics inquiry course to those who intend to graduate with either a science degree or a math degree with a physics minor. Readers will recall that the *teach*HOUSTON program is a joint initiative between the College of Natural Sciences and Mathematics and the College of Education at the University of Houston. This program provides secondary teacher certification for math and science majors who earn a Bachelor of Science/Arts degree in Math, Biology, Chemistry or Physics. The *teach*HOUSTON program is a strategic response to both our community's and the nation's critical shortage of high quality high school math and science teachers. Enrollment in *teach*HOUSTON, which started with 14 students in spring 2007, has swelled to 350 in fall 2010 and has produced nine graduates, eight of which are currently teaching in Houston-area schools and one who has begun graduate school.

Currently, there are eight physics majors enrolled in the program. With the Texas Higher Education Coordinating Board passing legislation which requires all high school students to complete four science courses including physics, to satisfy graduation requirements, there will be an even greater demand for physics teachers in the state of Texas. Currently, the majority of teachers in the 8-12 level are not trained in physics (those with a degree or a minor in physics); therefore, preparing highly qualified teachers is crucial if students are to be better prepared for college. Our goal is to increase the number of physics teachers as well as prepare current science and mathematics majors to teach physics through the physics inquiry course. Many of our biology majors take the state composite science certification test which certifies them to teach all sciences at the secondary level. Since the demand is strong for physics teachers, many graduates with biology majors may end up teaching physics or integrated physics and chemistry (IPC).

Careful consideration is crucial to determine where this course is best suited in the *teach*HOUSTON sequence of courses. Since *teach*HOUSTON replicates the UTeach program, we too have a curriculum to follow. Under the replication guidelines, *teach*HOUSTON is accountable to delivering their series of courses which currently does not include the physics inquiry course. As a result, this course can only be offered as an elective initially in the College of Education. Later, this course may be placed in the College of Natural Sciences and Mathematics where it can count as an upper level science elective which is currently where the UTeach program offers this course. Based on my personal experiences of teaching and researching physics taught as inquiry, I believe this course is best suited to occur between the third and fourth field-based courses. Field-based courses are those in which a preservice teacher works closely with a science mentor teacher in a local area school where the preservice teacher observes and teaches lessons in the mentor's classroom under the guidance of both the mentor teacher from the local school and the master teacher from *teach*HOUSTON. The *teach*HOUSTON program has four field-based courses prior to a semester long student teaching experience; the third and fourth field-based courses occur in local area high schools as opposed to the first and second field based courses where the experience is in elementary and middle schools. Because it might be beneficial to have a semester of developing and enacting lesson plans prior to the physics inquiry course, I believe this may be the best placement for this particular course. Based on the evidence I gathered as a consequence of my thesis research, I, as an educational leader, would recommend this choice.

In the fall semester of 2011, I plan to facilitate the physics inquiry course for undergraduate, pre-service teachers in a similar manner to the physics inquiry course taught to in-service teachers during the summer of 2010. What I learned generatively from the in-service inquiry teaching experience will definitely influence how I teach the undergraduate physics inquiry course. Since this course will be followed by a semester long course where preservice teachers will write and enact inquiry-based lesson plans, it is imperative that the instructor for the fourth field-based course is involved in the physics inquiry course so that the expectations for enacting the curriculum are coordinated. Moreover, it will be beneficial to discuss potential barriers to living inquiry-based learning as described earlier and to also discuss possible solutions to these barriers.

As leaders in the teaching of science, it is important to pave the way for teachers to be sources and facilitators of change instead of being targets and recipients of changes decided by others. Furthermore, science educators must serve as facilitators of learning instead of instructors and promote integration of theory and practice in school settings (NRC, 1996, p. 72). Studies such as this one have the potential to inform educational policy. For example, the teacher quality grant which funded the physics inquiry course is through the Texas Higher Education Coordinating Board and that body will review this doctoral thesis as part of the evaluation of this grant effort. Therefore, the results of this study may inform the office of Educator Quality and Preparation in their continuing effort to improve the preparation and quality of Texas educators. Additionally, because this study will inform the *teach*HOUSTON program, the first replication site of the UTeach at the University of Texas in Austin, conversations among UTeach and the various replication sites as to the importance of this course for undergraduate science teacher preparation programs can evolve. UTeach has garnered support and funding for replicating their program by the UTeach Institute, the National Math and Science Initiative, the Texas High School Project, the Texas Education Agency, The Greater Texas Foundation, Exxon Mobil Corporation, the Bill & Melinda Gates Foundation, The Michael & Susan Dell Foundation, Texas Instruments Foundation, The Tennessee Higher Education Commission, the Tennessee Department of Education, and other private philanthropies. As a result, UTeach and the UTeach replication sites such as *teach*HOUSTON are uniquely situated to influence the educational policy of Texas, other states such as Tennessee, and the United States as a nation.

Along with my role as a science master teacher in working with preservice teachers, I will also continue my work with in-service teachers. I was just notified that another round of funding was allocated to the University of Houston – Victoria teacher quality grant. As a result, I will have a further opportunity to teach a summer science inquiry course and subsequent professional development sessions. I plan to develop this next physics inquiry course utilizing McDermott's *Physics by Inquiry Volume II* (McDermott, 1996) and will once again reflect on last summer's experience to improve next summer's experience for in-service teachers. More specifically, I plan to devote more time to lesson planning, discussing barriers, and finding potential solutions to barriers that will work for those who wish to bring inquiry-based learning into their own teaching repertoires and into their own classrooms.

FINAL THOUGHTS

The gap between knowing science as inquiry and teaching physics as inquiry exists on many levels. There are teachers who learn through workshops that science concepts are best learned as inquiry but never personally experience learning science as inquiry which makes it difficult to enact inquiry-based learning in their classrooms. Readers will recall that changing one's mindset as to what an effective classroom should look like is a challenge; even when preservice and in-service mathematics and science teachers are prepared/cultivated in what arguably are "best practices," many still resort to teaching in ways that conflict with this preparation. In fact, many teachers revert to teaching the way they were taught (McDermott, 2007; Olson, 1995; Pereira, 2005; Windschitl, 2002). There are teachers who learn science as inquiry which enables them to better understand inquiry after being a participant of inquiry-based learning; however, many still experience difficulty in enacting inquiry-based lessons in their classrooms. To repeat and reinforce: The gap between knowing science as inquiry and teaching physics as inquiry has to do with the teacher as a learner and whether the teacher has brought that understanding into his/her teaching plotline and is desirous of living that plotline alongside students in secondary classrooms. Even when teachers desire to live an inquiry-based science curriculum alongside their students, enacting this in practice can be difficult without a fundamental support system in place. First, teachers must be charged to be curriculum makers by their administrators and preferably by school district personnel as well. As emphasized by NRC (1997), leaving the teacher out of the curriculum making equation encourages the teacher to be a consumer of knowledge about teaching instead of a producer of knowledge for teaching. In order for there to be change throughout the educational system, it is imperative that the teacher be a leader and a source and facilitator of change. Moreover, it is imperative that both preservice and in-service teachers are simultaneously afforded the opportunity to grow in inquiry-based teaching, which will better empower all to become curriculum makers, which is an inquiry in itself. Nevertheless, from a policy perspective, it is difficult to mandate something that is not lock-step, but rather generative. Also, it is important for teacher leaders to have a group of peers with whom to collaborate in enacting inquiry-based lessons in school settings. Mentoring both in-school and off-campus can also provide support for morphing the theory of inquiry-based learning into lived practice. Finally, it is important to understand that learning does not cease. The teacher who brings inquiry into his/her physics classrooms still seeks to improve/enhance their practice over time and needs peers and mentors with whom to continue the growth process. Just as the essential feature of classroom inquiry varies along a continuum, the teacher's development and professional needs along the continuum vary as well. Through on-going coaching/mentoring in a variety of professional development situations both on campus and off-campus, the journey of inquiry into inquiry can continue to evolve for teachers, colleagues, administrators, professional developers, and students, becoming increasingly generative and invitational as both time and situation unfold infinitely into the future.

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APPENDIX A: INQUIRY-BASED INSTRUCTION SURVEY

Inquiry-Based Instruction Survey

Name: ________________________
Years of Teaching Experience: ______
Grade Level /Subject ______________

1. What do you consider to be the key elements of inquiry-based instruction? In other words, how would you recognize inquiry-based teaching in a secondary science classroom?

2. Rank how much you agree with each of the following statements.

   a. In theory, inquiry-based instruction represents best practices in secondary science instruction; all instruction should be done in this format.

      Strongly agree   Agree   Disagree   Strongly Disagree

      Comment:

   b. In practice, inquiry-based instruction represents best practices in secondary science instruction; all instruction should be done in this format.

      Strongly agree   Agree   Disagree   Strongly Disagree

      Comment:

   c. Inquiry-based instruction represents one of a spectrum of valuable approaches to instruction. Good secondary science instruction should include both inquiry-based instruction and non inquiry-based instruction.

      Strongly agree   Agree   Disagree   Strongly Disagree

      Comment:

d. Inquiry-based instruction should serve as an overlay to traditional instruction, providing a connecting framework. It enhances traditional instruction but is not critical in secondary science classrooms.

Strongly agree Agree Disagree Strongly Disagree

Comment:

e. Inquiry-based learning is useful as a motivator to get students to learn material. Inquiry-based learning should serve as a reward in secondary science classrooms but is not a way to convey content to students.

Strongly agree Agree Disagree Strongly Disagree

Comment:

f. Inquiry-based learning is a distraction in secondary science classrooms. This format of instruction does not contribute to learning.

Strongly agree Agree Disagree Strongly Disagree

Comment:

3. Briefly describe how you plan to implement inquiry-based learning next semester (if at all). Please include the source for any curriculum materials you will be using.

4. What do you see as possible barriers to implementing inquiry-based learning into your classroom?

APPENDIX B: HEAT AND TEMPERATURE PRE- AND POST TEST

Name: ________________________

Heat and Temperature Pre/Post Test

1. In your own words explain what you think heat is. Try to say where your ideas come from.

2. In your own words explain what you think temperature is. Try to say where your ideas come from.

3. Suppose that you have two cubes of the same size, one made from wood and one made of metal. Both have been sitting in the room for some time. How do you think the temperatures of the two cubes compare? Explain your answer.

4. Suppose I have two bricks made from the same kind of clay, but one is large and the other is small. Suppose I put them both in an oven at 120°C for a few hours. At the end of a few hours, how will the temperatures of the two bricks compare?

5. Suppose I have a pot of boiling water on the stove. If I turn the stove up to a higher setting, what will happen to the temperature of the boiling water?

6. Suppose that 500 grams of hot water at 60°C is mixed with 500 grams of cold water at 40°C and the mixture is stirred.
    A. Will the temperature of the hot water *increase, decrease*, or *remain the same*? Explain.

B. Will the temperature of the cold water *increase, decrease*, or *remain the same*? Explain.

C. Will the temperature of the mixture be *greater than, less than or equal to 50°C?* Explain.

7. Now imagine that 500 grams of hot water at 60°C is mixed with 250 grams of cold water at 40°C and the mixture is stirred.

   A. Will the temperature of the mixture be *greater than, less than or equal to 50°C?* Explain.

8. Can a substance contain heat? Why or why not?

APPENDIX C: PARTICIPANT CONSENT FORM

UNIVERSITY OF HOUSTON VICTORIA
CONSENT TO PARTICIPATE IN RESEARCH

PROJECT TITLE: The Impact of an Inquiry-Based Course on the Beliefs and Practices of In-Service Teachers

You are being invited to participate in a research project conducted by the University of Houston Victoria Investigators. This research project will be part of a doctoral dissertation. This research project is being conducted under the supervision of Dr. Nora Hutto.

NON-PARTICIPATION STATEMENT

Your participation is voluntary and you may refuse to participate or withdraw at any time without penalty or loss of benefits to which you are otherwise entitled. You may also refuse to answer any question. If you are a student, a decision to participate or not or to withdraw your participation will have no effect on your standing.

PURPOSE OF THE STUDY

The purpose of this study is to examine outcomes related to C & I 6300. You have been asked to participate in the study because you are a participant in this class. The duration of the entire study will be from the time the participant enters the course until June 10, 2011. This study will address significant educational issues, primarily whether an inquiry-based science course, when successfully implemented, can increase the quality of science instruction.

PROCEDURES

You will be one of approximately 17 subjects to be asked to participate in this project.

If you agree to be in this study, we will ask you to do the following things:

- Participate in an interview/focus group.
- Take a pre-test and post-test over science content.
- Answer questions about your overall satisfaction with the course.
- Participate in journal writing as part of the C & I class.
- Write two inquiry lesson plans.
- Allow observations of lesson plans by researchers.
- Fill out an exit survey when you complete the course.

Total estimated time to participate is no longer than what is expected as a participant in the C & I 6300 class.

CONFIDENTIALITY

The following procedures and safeguards guide research staff in the protection of privacy and confidential information of study participants.

- The records of this study will be stored securely and kept confidential. Authorized persons from the University of Houston, members of the Institutional Review Board, and study sponsors, have the legal right to review your research records and will protect the confidentiality of those records to the extent permitted by law. All publications will exclude any information that will make it possible to identify you as a subject. Throughout the study, the researchers will notify you of new information that may become available and that might affect your decision to remain in the study.
- All data and materials, including recordings, will be kept for at least three years after the completion of the study.
- If you consent, the data resulting from your participation will be made available to other researchers in the future for research purposes not detailed within this consent form. In these cases, the data will contain no identifying information that could associate you with it, or with your participation in any study.

RISKS/DISCOMFORTS

The risk associated with this study is no greater than everyday life.

BENEFITS

There is no direct benefit of being in the study. However, you may be exposed to information that may help you in the future.

ALTERNATIVES

Participation in this project is voluntary and the only alternative to this project is non-participation.

PUBLICATION STATEMENT

The results of this study may be published in professional and/or scientific journals. It may also be used for educational purposes or for professional presentations. However, no individual subject will be identified.

SUBJECT RIGHTS

1. I understand that informed consent is required of all persons participating in this project.

2. All procedures have been explained to me and all my questions have been answered to my satisfaction.

3. Any risks and/or discomforts have been explained to me.
4. Any benefits have been explained to me.

5. I understand that, if I have any questions, I may contact Perri Segura at 713-743-4969. I may also contact Dr. Nora Hutto, faculty sponsor, at 362-570-4254

6. I have been told that I may refuse to participate or to stop my participation in this project at any time before or during the project. I may also refuse to answer any question.

7. ANY QUESTIONS REGARDING MY RIGHTS AS A RESEARCH SUBJECT MAY BE ADDRESSED TO THE UNIVERSITY OF HOUSTON COMMITTEE FOR THE PROTECTION OF HUMAN SUBJECTS (361-570-4374). ALL RESEARCH PROJECTS THAT ARE CARRIED OUT BY INVESTIGATORS AT THE UNIVERSITY OF HOUSTON ARE GOVERNED BY REQUIREMENTS OF THE UNIVERSITY AND THE FEDERAL GOVERNMENT.

8. All information that is obtained in connection with this project and that can be identified with me will remain confidential as far as possible within legal limits. Information gained from this study that can be identified with me may be released to no one other than the principal investigator, Perri Segura and her faculty sponsor, Dr. Nora Hutto. The results may be published in scientific journals, professional publications, or educational presentations without identifying me by name.

I agree to participate in this study. Yes _____ No ______

I HAVE READ (OR HAVE HAD READ TO ME) THE CONTENTS OF THIS CONSENT FORM AND HAVE BEEN ENCOURAGED TO ASK QUESTIONS. I

HAVE RECEIVED ANSWERS TO MY QUESTIONS. I GIVE MY CONSENT TO PARTICIPATE IN THIS STUDY. I HAVE RECEIVED (OR WILL RECEIVE) A COPY OF THIS FORM FOR MY RECORDS AND FUTURE REFERENCE.

Study Subject (print name): ____

Signature of Study Subject: ____

Date: ____

I HAVE READ THIS FORM TO THE SUBJECT AND/OR THE SUBJECT HAS READ THIS FORM. AN EXPLANATION OF THE RESEARCH WAS GIVEN AND QUESTIONS FROM THE SUBJECT WERE SOLICITED AND ANSWERED TO THE SUBJECT'S SATISFACTION. IN MY JUDGMENT, THE SUBJECT HAS DEMONSTRATED COMPREHENSION OF THE INFORMATION.

Principal Investigator (print name and title): ___________________________________

Signature of Principal Investigator: _______________________________________

Date: ____