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A PHENOMENOLOGICAL STUDY OF RURAL, HIGH SCHOOL STUDENTS' EXPERIENCES IN COGNITIVE APPRENTICESHIP METHODOLOGY

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Abstract

Presently the United States has a deficit of qualified STEM applicants and is relying on foreign students to relieve the shortfall. To relieve this deficit, members of underrepresented populations, such as women and minorities, must be recruited into STEM programs. Science foundations and institutions have endorsed the use of open-inquiry authentic research to help resolve the problem. Cognitive apprenticeship (Collins, Brown, & Newman, 1989) a social constructivist methodology, is a conceptual framework for implementing authentic research in science classrooms. It incorporates theoretic framework based on the literary works of John Dewey (1938/1997) and Lev Vygotsky (1978).

During the 2014-2015 academic year and the spring semester of 2016, two open-inquiry research projects took place at a remote, rural high school in Southeast Oklahoma. The projects, the Rhizobia and *Wolbachia* Projects, included twelve students. The projects required the students to learn advanced technical and cognitive skills. Six of the students agreed to participate in a phenomenological study (Moustakas, 1994) to document their feelings, perceptions, and impressions while they were in the projects. The interviews were transcribed, member-checked, and analyzed. Student recruitment for this study was based on participation in one or both projects, plus graduation from high school. Four of the students were female, and two were male. One was a foreign exchange student and one was Choctaw Native American. Five out of the six students in the study are now attending a university and majoring in STEM fields. Many of the students perceived they not only mastered the cognitive and technical skills, but the projects also helped to increase their confidence and organizational skills. Mastering these skills reassured them of their ability to be successful in a post-secondary STEM major.

Keywords: cognitive apprenticeship, phenomenology, open-inquiry research, project based learning, underrepresented populations

Chapter 1: Introduction

Over the last few decades, the United States has had to depend on foreign-born talent to fill many pertinent science and technology positions (National Science Board, 2012, 2015; National Science Foundation, 2010, 2015; President's Council of Advisors on Science and Technology, 2012). Since the former Soviet Union's successful launch of Sputnik in 1957, our country has seen periods of intense scrutiny, energy and talent put into education especially after the publication of such documents as *The Central Purpose of American Education,* (Educational Policies Commission, 1961) and *A Nation at Risk* (National Commission on Excellence in Education, 1983). These surges of energy and talent have inspired innovative students to enter the fields of science and technology and have served this country well (National Science Board, 2010, 2015). It led to many new advances in industries, and job opportunities. However, these periods soon led to a time of complacency and a decline in the number of students entering science, technology, engineering and mathematics (STEM) fields (National Science Board, 2010, 2012, 2015).

For the U.S. to remain globally competitive in the 21st century, our country must recruit and maintain the most innovative, talented and motivated students to enter the STEM career fields, especially from the underrepresented segments of our society such as women and minorities (National Academy of Engineering, and Institute of Medicine, 2011; National Science Board, 2015; Foundation, 2010; President's Council of Advisors on Science and Technology, 2012). Thus far, we have not been successful. Recruitment levels are stagnant (Korn, 2015; National Center for Education Statistics, 2014). Also, the attrition rate of STEM majors in postsecondary institutions continues to increase (National Center for Education Statistics, 2014).

In 2004, only 33% of all postsecondary students were enrolled in STEM career fields (Korn, 2015; National Center of Educational Statistics, 2014). This number will have to double in order to meet the demand for STEM professionals (President's Council of Advisors on Science and Technology, 2012). Business Roundtable (2008), a group of sixteen major business organizations, also projected that America would have to double the present rate to remain competitive with China, India, and other economically emerging nations. However, in 2014, the percentage of students in STEM postsecondary degree programs had only increased by 1% (Korn, 2015; National Center of Educational Statistics, 2014). The U.S. has one of the lowest ratios of STEM to non-STEM bachelor's degrees in the world (National Science Board, 2012). In 2014, the government projected there will be 2.4 million STEM job openings by 2018. Of these job openings, 1.1 million will be new job openings, and 1.3 million will be replacement openings (Carnevale, Smith, & Melton, 2014).

Oklahoma alone will have 75,400 STEM job openings by 2018, and 89% of these jobs will require postsecondary education. The vast number of these job openings will be in computer engineering (Carnevale et al., 2014). The rate of students entering computer engineering and mathematics is especially disturbing; six percent of all STEM students major in these fields. The numbers are exceptionally low for women and minorities (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2011; National Center of Educational Statistics, 2014; National Science Board, 2010, 2015). Gains have been made for women and minorities entering the biological sciences and medical fields, but still the majority of students completing STEM degrees are white males (Business Roundtable, 2008; Korn, 2015; National Center of Education Statistics, 2014). Seventy percent of undergraduates are women and minorities, but only 45% of those students are in STEM degree programs (President’s Council of Advisors on Science and Technology, 2012).

Attrition is also a problem. Between 2006 and 2009, 69% of students pursuing associate’s degrees in STEM fields and 48% pursuing bachelor's degrees either changed majors to non-STEM degrees or left college before earning a degree (National Center for Education Statistics, 2014). The attrition rate for women and minorities is exceptionally high (Graham, Frederick, Byars-Winston, Hunter & Handelsman, 2013). For example, African-American students who declare STEM majors upon entering college switch to non-STEM majors at twice the rate of white students (Graham et al., 2013).

Major factors affecting STEM recruitment and attrition include (a) lack of authentic scientific research experiences (American Association for the Advancement of Sciences, 2017; Committee on Science and Technology, 2007; National Science Board, 2015; National Science Teachers Association, 1998; Oriz & Sriraman, 2015); (b) lack of high school academic preparation, especially in mathematics (Dika & D’Amico, 2016; Goldman, et al., 1976; Hackett & Betz, 1981; Sells, 1973); and (c) differences between the culture of science and the social culture of the students (Aikenhead, 1996, 1998; Costa, 1995). Recommendations for eliminating or decreasing the prevalence of these factors have been addressed in the literature. In a major study funded by the National Science Foundation to ascertain why women and minorities are leaving or not entering STEM fields (Trent & Baber, 2015) and ways to reverse this trend, several solutions were proposed based on tracking enrollment at universities, analyzing interventions and documenting student experiences. The solutions included early exposure, in middle and high school, to conducting research, exposure to rigorous, quality courses to eliminate inadequate academic preparation, and promoting student development of a "science identity" (Trent & Baber, 2015). The American Association of University Women (AAUW) also advocates early research opportunities for students (Hill, 2015). They cited an example from Harvey Mudd College which has increased the number of women majoring in computer science by from 12 % to 40 % by implementing early research, required introductory computer science courses, and exposure to Grace Hopper Celebration of Women in Computing (Hill, 2015). In 1998, the National Science Teachers Association published a position paper on the need for a scientifically literate populace including guidelines for achieving this goal. The paper presumed that an increase in science literacy would also increase the number of individuals entering STEM fields (National Science Teachers Association, 1998). Besides outlining the need for teacher support and professional development, the paper also detailed the need for students to engage in open-ended inquiry, which results in the students being intellectually challenged to formulate their own research questions, and to develop their own methods resulting in data that support or do not support a hypothesis (National Science Teachers Association, 1998). Open-ended inquiry has been defined as inquiry where students have been given an educational framework in which to work; however, the research questions, data analysis and methods, etcetera are all student driven. The students are constantly in a decision-making process similar to that of research scientists. The teacher is there only to help guide them through the processes and be part of the team (Zion & Mendelovici, 2012). These guidelines for supporting open-ended inquiry based instruction, plus schools' need for technical, professional and monetary support have all been endorsed by major science foundations, organizations and agencies (American Association for the Advancement of Sciences, 2017; Committee on Science and Technology, 2007; National Science Board, 2015; National Science Teachers Association, 1998)**.**

Statement of the Problem

The U.S. has a deficit of natural-born and/or naturalized citizens entering STEM fields of study (National Science Board, 2010, 2012, 2015; President's Council of Advisors on Science and Technology, 2012). Not only is recruitment a problem, attrition is problematic also. The recruitment rates of underrepresented populations, women and minorities, into STEM fields is especially low and their attrition rates are high (Graham, et al., 2013; National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2011; President's Council of Advisors on Science and Technology, 2012). Lack of authentic science research experience (Committee on Science and Technology, 2007; Oriz & Sriraman, 2015), lack of high school preparation (Dika & D'Amico, 2016; Goldman, et al., 1976; Hackett & Betz, 1981; Sells, 1973) and differences between the students' social cultural worlds and the culture of science are the major underlying factors (Aikenhead, 1996, 1998; Costa, 1995) that contribute to this deficit.

These three factors have been identified as discriminators in undergraduates' choices of science versus non-science majors, especially in underrepresented populations (Astin & Astin, 1992; Betz, 1978; Dika & D'Amico, 2016; Goldman, et al., 1976; Hackett & Betz, 1981; Reason, 2009; Sells, 1973). Lack of authentic scientific research has its root cause in a deficiency of technology, insufficient teacher education and support, plus low funding of American schools (Gordin & Pea, 1999). Furthermore, extensive mathematics skills are required for a career in science. Underrepresented populations are less likely to take rigorous academic courses and/or additional mathematics courses above the requirements for high school graduation (Dika & D'Amico, 2016; Sells, 1973). Often, minorities are placed in lower level and remedial courses in high school which do not prepare them for college (Astin & Astin, 1992; Crisp, Nora & Taggart, 2009). Also, "gateway science courses" whose goal it is to separate students by their ability or lack of ability to succeed in STEM majors, are aggressive, competitive and large. Many women and minority students are discouraged from pursuing advanced STEM courses because of these gateway courses (President's Council of Advisors on Science and Technology, 2012).

Western science, a subculture of Euro-American culture (Aikenhead, 1996), differs greatly from the social cultures of many underrepresented populations (Costa, 1995; Phelan, Davidson & Cao, 1991), especially the indigenous populations (Aikenhead, 1996, 1998). The culture of science tends to be masculine, competitive, empirical, mathematical and rational (Aikenhead, 1998). Studies indicate that the cultural social worlds of minority status students are often very distant from that of science. The term "cultural borders" has been used to refer to the boundaries of these cultural worlds (Costa, 1995; Phelan, et al., 1991). It has been hypothesized that the greater distance there is between a student's cultural world and that of science, the more difficult it is for them to the cross cultural borders into the world of STEM (Costa, 1995; Phelan, et al., 1991). Additionally, indigenous students, whose cultural beliefs often revere the mystery of life and nature, have to find some way to rectify the analytical nature of Western science with the cultural beliefs of their tribes (Aikenhead, 1995, 1998). These differences in cultures explicitly mean that values, goals, and social relationships of the students' families, peers, and teachers are different than those of science professionals. Therefore, there is a deficit of encouragement and support from teachers, parents and peers for students in these underrepresented populations (Goldman et al., 1976; Ortiz & Sriraman, 2015; Sell, 1973).

If the U.S. is serious about increasing recruitment and decreasing attrition of underrepresented populations in STEM postsecondary fields of study, the problem of eliminating these three factors that will have to be addressed. The American Association for the Advancement of Sciences (2017) specifically endorses conceptual framework methodologies that incorporate authentic science research in classrooms. However, there are relatively few studies that have used this method of teaching in American middle and high school science classes (Collins, et. al. 1991a; Roth, 1991; Putica & Trivic, 2016; Charney, Hmelo-Silver, Sofer, Neigeborn, Coletta & Nemeroff, 2007). Exactly, what are the lived experiences of students, especially those from underrepresented populations, who have participated in projects taught in cognitive apprenticeship methodology? How do they think this experience has impacted their lives and the choices they made in post-secondary education? What commonalities or patterns were ascertained from documenting their experiences?

A literature search using ERIC (EBSCO) and Google scholar was conducted with the following terms: cognitive apprenticeship, cognitive apprenticeship in high school science, cognitive apprenticeship and minority students, cognitive apprenticeship and underrepresented populations, cognitive apprenticeship and women, cognitive apprenticeship in high schools, cognitive apprenticeship in rural schools, cognitive apprenticeship and authentic research, plus phenomenological studies on cognitive apprenticeship. Using these two search engines with these search phrases did not produce any phenomenological studies that documented the lived experiences of remote, rural students who have participated in high school science courses and/or projects taught with cognitive apprenticeship.

Background and Need

The necessity of a scientific literate populous cannot be overstated if our country is going to remain competitive in today's global market. An increase in science literacy should be reflected in an increase in the number of students entering STEM fields (National Science Teachers Association, 1998). The rate of science literacy in our population is an indication of the science achievement of our high school students. However, the science achievement of American students has remained almost unchanged for the last three decades (National Research Council, 2006). The science literacy rate of adults in our country has only increased from 10% to 17% between 1980 and 1999 (Miller, 2004).

Today, too many high school science courses are comprised of various units of study, taught in expository style with very little scientific reasoning or experimentation (National Academies of Sciences, Engineering, and Medicine, 2015). Numerous classes focus on low-level rote memorization and/or use "cookbook" experimental procedures insuring pre-determined results neither of which promote critical thinking skills (Oaks, 2000). Scientific research foundations, scientists and educators have all studied this situation. Most agree science education must change from traditional teaching methods to open-inquiry, social constructivism learning in order to increase science literacy and the number of students entering STEM fields (National Academies of Sciences, Engineering, and Medicine, 2015; Oaks, 2000; Zion & Mendelovici, 2012). Open inquiry authentic scientific research in high school classrooms is being advocated to teach scientific thinking, reasoning, experimentation, collaboration, and biotechnology skills (American Association for the Advancement of Sciences, 2015; Krajcik, Blumenfeld, Marx, & Soloway, 2015; National Science Board, 2010).

Research states that authentic research is a powerful tool for engaging students, stimulating their curiosity, encouraging professional identification and enculturation into the scientific community. It also stimulates students to develop a deeper understanding of mathematics and the intricacies of scientific writing (American Association for the Advancement of Sciences, 2017; Committee on Science and Technology, 2007; National Science Board, 2015; National Science Teachers Association, 1998). However, even though authentic research is said to provide the optimal opportunities for cognitive development and scientific reasoning, guided and/or simple inquiries are generally used in classrooms (Crawford, 2000; National Academies of Sciences, Engineering, and Medicine, 2015). All too often, students study the scientific achievements of others rather than experiencing the allure of real scientific research (Committee on Science and Technology, 2007; Graham, et al., 2013).

What constraints are preventing science classrooms from using authentic research methods? There are multiple challenges to changing from structured classrooms to open inquiry classrooms, such as the lack of teacher knowledge, training and support, the lack of funding and equipment, and of upmost importance, the lack of a conceptual framework to implement open inquiry authentic research (National Research Council, 2006; Gordin & Pea, 1999; Zion & Mendelovici, 2012). Many teachers who have tried to implement authentic research into the classroom are not successful due to the lack of a conceptual framework (Kelly & Knowles, 2016). Cognitive apprenticeship methodology, which uses social constructivism as its theoretical framework, is one conceptual framework that supports open inquiry research teaching (Association for the Advancement of Science, 2015). Very few studies have been done in the U. S. on cognitive apprenticeship methods in science classrooms (Collins et al., 1991a; Charney, Hmelo-Silver, Sofer, Neigeborn, Coletta & Nemeroff, 2007; Putica & Trivic, 2016; Roth, 1991). No studies have been found that document the students' impressions, feelings, and perceptions of participating in projects taught with cognitive apprenticeship. What actually are the lived experiences of these students? How do they believe it affected them? Do they believe there was a correlation between participating in these projects and their choices in post-secondary school or in the workforce?

Purpose of the Study

The purpose of this phenomenological study (Moustakas, 1994) is to document the lived experiences of remote, rural students, most of them underrepresented minorities, who participated in high school science projects taught with cognitive apprenticeship methodology (Brown, Collins, & Duguid, 1989; Collins, 2006; Collins et al., 1991b; Collins et al., 1989; Collins, Hawkins, & Carver, 1991a). This study recorded the students' impressions, feelings, and perceptions about these experiences. The projects that utilized cognitive apprenticeship methodology addressed two of the major factors previously stated as underlying reasons women and ethnic minority students do not enter into STEM majors and/or careers. These are lack of authentic scientific research and differences between students' cultural social world and that of science. These projects partially addressed the lack of high school preparation through analysis of data, in addition to reading and writing research papers. Through cognitive apprenticeship methodology the students took part in authentic scientific research and became enculturated into the cultural world of science, thus decreasing the distance between the two social worlds' cultural borders (Aikenhead, 1996, 1998).

Despite the U.S. imbalance between qualified STEM applicants and STEM job openings, the number of students in postsecondary STEM education is stagnant and the attrition rate is high (National Center for Educational Statistics, 2014). Using cognitive apprenticeship methodology in high school science classes may encourage students to enter postsecondary STEM education fields plus increase the level of science literacy in our populous. At the very least, it should help them gain the academic tools needed to persevere and succeed in university science courses.

The first project, the Rhizobia Project, took place during the 2013-14 school year. The second project, the *Wolbachia* Project, was taught during the spring semester of 2016. Twelve students participated in the projects, two could not be reached to be interviewed, two are single working mothers of newborns and did not think they could find the time to be interviewed, one recently died in an automobile accident, and seven consented to be interviewed. However, one student who consented verbally to be interviewed did not return the signed consent form. Thus, six former students comprised the participant group for this study. All of the students interviewed have graduated from high school. Most of them are attending universities. The interviews lasted approximately 45 minutes, with the option of a second interview if more information was needed. Interview questions were divided into three sections, (a) their present situation, (b) the Rhizobia Project, and (c) the *Wolbachia* Project. Not all of the students participated in both projects. The interviews were semi-structured with open-ended questions.

Research Questions

The overarching question of this study was: what were the lived experiences of students participating in authentic scientific research that was guided by cognitive apprenticeship methodology? In addition, the following sub-questions further guided the research on this topic:

1. What were the impressions, feelings, and perceptions of these students while participating in the projects?
2. What commonalities or patterns were found in these experiences?
3. How did the students' experiences influence their lives, especially in their choices to pursue post-secondary education?

Definition of Terms

The following terms will be used throughout this research study:

Articulation – a component of cognitive apprenticeship where the teacher uses different methods to encourage students to verbalize their knowledge, thinking, reasoning, or problem-solving processes (Collins et al., 1989)

Coaching – a component of cognitive apprenticeship where the teacher observes students performing a task and then offers feedback and suggestions to improve their performance (Collins et al., 1989)

Epoché – also called bracketing or phenomenological reduction, is the art of refraining from any judgement or conclusion for or against something (Moustakas, 1994)

Exploration – a component of cognitive apprenticeship where the teacher invites students to pose, solve their own problems, and create their own methods to solve problems; used actively in open-inquiry teaching (Collins et al., 1989)

Modeling – a component of cognitive apprenticeship where the teacher, being the master or expert, performs a task in a certain domain so the novice or students can observe and ask questions for the purpose of learning to perform the task themselves (Collins et al., 1989)

Noema – the phenomenon one experiences (Moustakas, 1994); an object of perception or thought, as opposed to a process or aspect of perceiving or thinking (Oxford English Dictionary, 2017)

Noesis – the way in which the phenomenon is experienced (Moustakas, 1994); the subjective aspect of an intentional experience, as opposed to the noema (Oxford English Dictionary, 2017)

Reflection- a component of cognitive apprenticeship where the teacher enables students to compare their performance, problem solving techniques, critical thinking strategies, with that of others especially masters or experts (Collins et al., 1989)

Scaffolding – a component of cognitive apprenticeship where the teacher provides support in the form of questions, suggestion, and/ or activities to facilitate the students' mastery of a skill or task (Collins et al., 1989)

Limitations

There are several limitations in this study. Firstly, the researcher taught the two projects, interviewed the participants, and analyzed the interviews thus there is a potential for researcher personal bias. Secondly, the students might have experienced difficulties objectively answering the interview questions due to their allegiance to me. Thirdly, the amount of time between the project participation and the interviews and the project participation may also be a limitation. The Rhizobia Project took place five years ago, and the *Wolbachia* Project took place two years ago. Some of the students may not clearly remember their feelings. For a phenomenological study to be as objective as possible, Moustakas (1994) encouraged researchers to reflect and describe their own experiences with the phenomenon, or in other words, to practice Epoché. This I have done in Chapter Three.

Ethical Considerations

Few ethical issues were anticipated. All individuals who could be located and participated in either of the two projects, or both, were invited to participate in this research project. Participation was voluntary. The participants included two males and four females. The interviews lasted approximately 45 minutes, were recorded on a smart phone, and then transcribed non-verbatim. The recordings were erased at the end of the study. There were no photographs or video recordings made. All information was kept confidential and anonymous. No information in the research makes it possible to identify the participants. Research records were stored securely and only approved researchers and the OU Institutional Review Board had access to the records. Member checking was used for the interview transcriptions. Participants had the opportunity to view the information collected about them. There were no risks or benefits to the participants other than helping to advance the teaching of science in high schools.

Chapter 2: Review of the Literature

Global competitiveness in an increasingly complex and technologically sophisticated world requires an ample pool of qualified STEM applicants. At present, the U.S. is deficient in this area, and the deficit is not going to change in the foreseeable future (National Science Board, 2010, 2012, 2015; President's Council of Advisors on Science and Technology, 2012). We have one of the lowest ratios of STEM to non-STEM majors in post-secondary schools of all the developed nations (National Science Board, 2012). To eliminate this deficit, recruitment of women and minorities into STEM fields must increase. Progress has been made in biological and medical fields, but recruitment of these underrepresented populations is especially low in computer engineering, physics, and mathematics (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2011; National Science Board, 2010, 2015; National Center of Educational Statistics, 2014). Between 2004 and 2014, the number of students majoring in STEM related fields has only increased by 1% (Korn, 2015; National Center of Educational Statistics, 2014). Not only is recruitment a problem, attrition is also a major problem. During the three-year period from 2006 to 2009, 48% of students pursuing a bachelor's degree in STEM fields and 69% in associate degree STEM programs, either left school or changed to a non-STEM major (National Center for Education Statistics, 2014).

For these statistics to change, our schools must shift from instruction-based learning to social constructivism, which facilitates collaborative-based inquiry learning. The highest level of inquiry-based learning is open inquiry (Zion & Mendelovici, 2012), which simulates the types of research and experimentation that is performed by scientists. Open inquiry demands higher level critical thinking (Zion & Mendelovici, 2012).

Theoretical Framework: Social Constructivism

Social constructivism advocates the construction of knowledge through social interactions (Atwater, 1996; Vygotsky, 1978). The importance of social interaction and experience in education was first associated with Dewey (Dewey, 1938/ 1997). Additionally, Lev Vygotsky, whose work was unknown to the Western world until 1978 (Shotter, 1989), identified socialization as having a premier impact on the construction of knowledge (Dimitriadis & Kamberelis, 2006; Vygotsky, 1978).

John Dewey.

Dewey is probably the person most Americans associate with American public education; his reputation is world renowned; and his legacy is uncontested (Vandervoort, 1983). Dewey stated that the purpose of education is the intellectual, social, moral and emotional development of an individual in a democratic society (Dewey, 1938/1997). This statement epitomizes Dewey's pragmatist approach to education. If the United States was to maintain a viable democracy, then it needed to establish a relevant, experience based educational system.

Dewey also clearly defined his views on education, school, and their importance to the well-being of society in *My Pedagogic Creed*, published in 1897 (Dewey, 1897). Education is needed to give students the full potential of their abilities so that they can accurately evaluate their environment and then use their capabilities and talents to lead relevant, successful and positive lives; lives that will not only benefit themselves, their family, and their colleagues, but will also be a positive force in our democracy (Dewey, 1897). A child’s education must begin with, and continue to be based on their capabilities, interests, and habits (Dewey, 1987). Education is far less valuable to a student if it is based on preparation for the future. “Education is living, not preparation for future living” (Dewey, 1897, p. 78). In an industrialized world, no one can tell what civilization will be twenty years from now (Dewey, 1897).

Dewey’s experiential continuum theory (Dewey, 1938/1997) is very explicit on both the need for experience in education and the importance of science education to the general public. Experience is needed in all educative endeavors. These experiences need to be designed around the interests of the child, one experience builds on the next with each becoming increasingly difficult and more complex. It is the emphasis on the quality of the experiences that matters; there is no room for improvisation (Dewey, 1938/ 1997). Structure is essential. Educational experiences must be based on relevance to the child plus a grounding to the past and future (Dewey, 1938/ 1997). Experiential continuum theory emphasizes both the need for continuity and interaction. Every educative experience brings with it some element of the last educative experience, which then will impact the next educative experience. Without this, experiences are mis-educative. Educative experiences not only build on one another using the interests of the child as a foundation, they also interact with the child’s past experiences. They facilitate intellectual growth, the development of new skills, moral growth, arouse curiosity, plus increase initiative and purpose (Dewey, 1938/ 1997).

Education needs to be active and social. The interests of the child are the center and the embryonic structure on which the curriculum needs to be built. Not that the child should be left to his own instincts, but rather these instincts should be used to nurture both the psychological and sociological development of the child (Dewey, 1897). Education should be seamless, not divided into subjects as if these subjects had no relationship to each other. While at home, the child's world is seamless, warm, and caring. School should be the same; one subject melds into another, both seamless and relevant (Dewey, 1907/ 2009).

Dewey's educational theory viewed the school as a microcosm of world outside. Students' adjustment to school should prepare them for the society. Social skills, collaboration, mentoring, and learning prepare one for life in society (Dewey, 1907/ 2009). The theory is as relevant today as it was yesterday.

Lev Vygotsky.

Lev Vygotsky was the founder of cultural-historical psychology and the concept of zone of proximal development (ZPD). His work was translated from Russian to English in the 1970's (Shotter, 1989). After the translation, many scholars either refused to embrace his theories or were confused by them (Shotter, 1989). Vygotsky felt social interaction had the greatest impact on intellectual development of the child, not the child's biological make-up, egocentrism, or the manipulation of objects (Dimitriadis & Kamberelis, 2006). This may relate to the differences between the philosophies of the cultures. Western cultures tended to align with individualism and capitalism, whereas Eastern cultures tended to align with socialism (Shotter, 1989).

Vygotsky's theory of development places great emphasis on the child's culture, socialization and cognitive development. His theories emphasized social and semiotic mediation (Dimitriadis & Kamberelis, 2006). Semiotics is the study of the relationship between signs, symbols, and meaning. Vygotsky theorized that we learn language, symbols and signs to communicate our ideas (Dimitriadis & Kamberelis, 2006). However, the actual meaning of our communication cannot be found in the original spoken work, or in the reception of the original concept. The actual meaning of the concept is found in the social dialogue between the speaker and the listener (Shotter, 1989). Learning occurs first through the social relationships with more knowledgeable individuals, and then is internalized. Internalization is the process where the activity leads to the enculturation of the individual. Thus, the activity along with the association of cultural signs and symbols is internalized and becomes part of the individual's culture (Dimitriadis & Kamberelis, 2006).

The zone of proximal development (ZPD), a central theme in Vygotsky's work, is defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). The mental developmental level of a child is the level that can be determined by diagnostic testing on the child's independent capabilities (Vygotsky, 1978). However, each child has a ZPD. The ZPD is what the child can accomplish with the synergistic collaboration and/or the guidance of a teacher. The construction of knowledge comes from the intercommunication with more knowledgeable individuals. Examples of synergistic knowledge are imitation of language, sign and symbols, and imitation of actions to learn a skill (Vygotsky, 1978). A child's mental development should not only be based on what they can accomplish alone. Two children might be on the same actual developmental levels. However, with guidance and social collaboration one child might be capable of accomplishing tasks at a higher level than the other. This can be interpreted as showing that one child is on a higher ZPD than the other (Vygotsky, 1978). The ZPD was a totally original concept to Western theorists. Vygotsky's theory of development has enriched Western philosophy and has had multiple applications for educational theory (Seng, 1997).

Conceptual Framework: Cognitive Apprenticeship

Cognitive apprenticeship is a conceptual framework for conducting open inquiry investigations in the classroom as it employs structured experience and socialization in the form of modeling, coaching, scaffolding, articulation, reflection, and exploration (Collins et al., 1989). Masters and apprentices come together to form a "community of practice" where cognitive and metacognitive skills are visible, verbal, and used for the accomplishment of specific factual goals (Collins, 2006; Collins et al., 1991a; Collins et al., 1989; Collins et al., 1991b).

Cognitive apprenticeship, which was proposed by Collins, Brown and Newman (1989), uses the theoretical framework of Dewey and Vygotsky as its theoretical underpinning. Cognitive apprenticeship states that students can learn cognitive and metacognitive skills and processes in a similar way that masters have been training apprentices in manual trades for centuries (Collins, 2006; Collins et al., 1989; Collins et al., 1991a; Collins et al., 1991b). The processes to be learned are the cognitive and metacognitive skills experts use to decipher complex tasks, such as protocol analysis and problem solving. These, in turn, foster conceptual and factual knowledge that facilitates deeper correlation between the solution and the problem in context of a real-world environment (Collins et al., 1989). Additionally, the mental processes used by experts are verbalized in conversations between mentors and apprentices which makes the protocols of problem solving apparent. Whereas normally, the problem-solving processes would be mental steps carried out by the mentors. “Cognitive apprenticeship teaching methods are designed to bring cognitive and metacognitive processes out into the open, where students can observe, enact, and practice them with help from the teacher and from other students” (Collins et al., 1989, p. 458).

Figure 1 (see page 22) aligns cognitive apprenticeship (Collins et al., 1989) as the conceptual framework with both Dewey’s and Vygotsky’s theories as the theoretical framework. Dewey’s Experiential Continuum Theory (Dewey, 1938/1997) espouses the need for educative experiences that increase in difficulty, along with socialization. Vygotsky’s ZPD also recommends socialization for a child to reach his/her ultimate level of mastery (Vygotsky, 1978). In cognitive apprenticeship, the master teacher uses methods such as modeling, coaching, scaffolding, etcetera to help the student apprentices develop the metacognitive and cognitive skills needed to master the complex challenges. The cognitive apprenticeship methodology aligns with socialized learning by creating a “community of practice” where masters and apprentices comes together to collaborate to solve increasingly complex problems.

Theoretical Framework	Conceptual Framework
Experiential Continuum Theory (Dewey)	Cognitive Apprenticeship Theory (Collins, Brown, & Newman)
Educative Experiences	Modeling, Coaching, Scaffolding, Exploration, Increasing Complexity, Increasing Diversity from Local to Global
Socialization	Situated Learning, Community of Practice, Peer Teaching for Articulation & Reflection, Collaboration
Sociocultural Theory of Cognitive Development (Vygotsky)	
Zone of Proximal Development	Situated Learning, Peer Teaching for Articulation & Reflection, Collaboration, Increasing Complexity
Culture	Community of Practice

Figure 1. Alignment of theoretical and conceptual framework

Cognitive Apprenticeship Methodology

Relatively few empirical studies have been found that incorporate cognitive apprenticeship methodologies in science education. ERIC (EBSCO) and Google/ Scholar were mainly used to search for empirical studies. Topics used in the search were cognitive apprenticeship in high school science, cognitive apprenticeship, cognitive apprenticeship and biology, cognitive apprenticeship in rural high schools, phenomenological studies of cognitive apprenticeship in high school science, and cognitive apprenticeship in underrepresented populations. Of those studies, most evaluated the influence of cognitive apprenticeship versus other teaching methods. Three of the studies have occurred overseas (Bouta & Paraskeva, 2013; Chiu, Chou, &

Liu, 2002; Tsai, Jack, Huang & Yang, 2012). Four studies took place in the United States (Collins, et. al. 1991a; Roth, 1991). Two of the studies made references to minorities and/or women as a group, but not singularly (Charney, et al., 2007; Collins et al., 1991a). All of the studies attempted to evaluate some combination of students' scientific skills such as problem solving and reasoning, motivation, STEM self-efficacy, and in-depth understanding of scientific concepts.

Cognitive Apprenticeship Studies

In a quasi-experimental preliminary study (Collins et al., 1991a) using cognitive apprenticeship methodology as the intervention, five types of scientific skills were targeted for urban students from Harlem and Rochester, New York. They included question posing, data gathering, data interpretation, data representation, data presentation and evaluation. This study introduced authentic research using cognitive apprenticeship methodology into the schools. One high school, a middle school, and a few elementary "feeder" schools were involved. Most of the students were African-Americans, low SES, and the majority had been labeled "at risk" (Collins et al., 1991a).

The "Discover Rochester Project" at Charlotte Middle School is a suitable example of the New York school system's preliminary study using cognitive apprenticeship, its educational organization, and the results of the preliminary study (Collins et al., 1991a). All classes were taught using the cognitive apprenticeship model. The school year was broken into trimesters. Students were accepted into the program on a first come, first serve basis. Previous scores from mandatory testing were not included in the process. Students had two, two-hour block periods per day. One was for mathematics/science, and the other was for the humanities. All subjects were taught across the curriculum (Collins et al., 1991a). Students had ample access to computers to conduct their research. The few single periods between the two block periods were used for physical education, lunch and student/ teacher mentoring. Teachers met for staff development with their teams a half day each week. Each teacher was assigned no more than sixteen students per class to enable a close mentoring environment. Team teaching was encouraged (Collins et al., 1991a).

One day each week, small groups of students and teachers would explore aspects of the Rochester environment looking for scientific, mathematical, historical, cultural, and literary perspectives to investigate. After research areas were identified, students divided into small research groups to decide on projects. Students also took an active role in directing their own learning. Each project had to include a presentation of some type, articulation of research, collaboration, and some written artifact (Collins et al., 1991a).

Researchers observed “impressive improvement” of student intrinsic motivation during the project. At the start of the project, students were “sluggish, uncooperative, and unimaginative”. Some students were silent. “The initial brainstorming session was more a lesson for the teachers in pulling teeth” (Collins et al., 1991a, p. 186). As the program progressed student behavior, self-efficacy, motivation, and academic skills increased far beyond expectations. These improvements were documented from informal, researcher observations. The success of this pilot study led to empirical studies being funded to evaluate the cognitive apprenticeship project-based model. The results of the follow-up studies were not published (Collins et al., 1991a).

An interpretive methodology study was designed (Roth, 1991) to validate the need for authentic research in the classroom using the cognitive apprenticeship model. Traditional teaching methods give students the impression that science is invariant, but nothing could be further from the truth (Roth, 1991). There are vast discrepancies between how science is taught in schools, and how scientists solve "real-world problems". Students are rarely given a glimpse of the hard-experimental work, the disappointments and the exhilaration of finding a solution that scientists' experience (Roth, 1991).

Three classes of eighth grade students from an urban private school were divided into groups of two or three students. The ethnicities and SES level were not given. Their teacher, who acted as the mentor/ facilitator, had a bachelor's degree in biology and another in education plus had almost completed a master's degree in biology. The ten-week study investigated micro-organisms on different 5 x 10-meter plots of ground. The investigative topic was given to the students, but not the research questions or procedures. These were generated by the students. A lottery was used to assign the plots (Roth, 1991). As the study progressed, the students' questioning processes became increasingly more sophisticated, proficient problem-solving skills developed, hypotheses showed complex higher-level thinking, collaborative skills improved, scientific vocabulary became incorporated into discussions, and students' ability to present their data in graphs revealed in-depth understanding of their results. Moreover, the students' self-efficacy and motivation increased because they had formulated the research questions and procedures themselves. These results were based on audiotaped interviews of the students and their teacher (Roth, 1991).

This qualitative study was well-done and adhered to the principles of cognitive apprenticeship but could have been strengthened by the additional of quantitative data. Also, exactly how the interviews were evaluated to conclude an increase in self-efficacy and motivation was not given. From analyzing the interviews three assertions were made. Firstly, the students engaged in and developed sustained research programs that gradually facilitated the development of high levels of sophistication. Secondly, the students developed a wide variety of complex research and analysis skills. And thirdly, students constructed new ways to represent, and communicate the results of their research (Roth, 1991).

Conceptualizing chemical models has been shown to be difficult for many students. To investigate students' ability to develop mental models of chemical equilibrium, Chiu, Chou, and Liu (2002) developed a study using the cognitive apprenticeship model for 30 tenth grade students in Taiwan. These thirty students were selected, out of a group of 122, because of their confused and/or inaccurate statements regarding chemical equilibrium. The students were randomly divided into three classes. Pretests and posttests were given. Also, randomly picked students from the three classes were extensively interviewed. Ten students were in the control group and were taught by traditional experimentation by a tutor (Chiu, et al., 2002). The other 20 students were instructed using the cognitive apprenticeship model. All students were encouraged to collaboratively complete and actively explore the experiments available. However, the experimental group were required not only to actively and collaboratively explore with experimentation, but also required to reflect and articulate their cognitive and metacognitive processes to their classmates (Chiu, et al., 2002).

Instruments included a pre- and posttest with 13 major items on each. The instruments were reviewed by the Department of Chemistry at a local university for validity. The pretest had a reliability Cronbach alpha rating of 0.70 and the posttest 0.78. The results showed that the cognitive apprenticeship group significantly outperformed the traditional group in constructing mental models, including random and dynamic activities of molecules plus molecule interactions. The study was extremely well-done giving a breakdown of chemistry concepts students struggled with along with interview excerpts which detailed students thought processes. This study did not recommend future use of cognitive apprenticeship but did say it gave them a clearer vision of how students learn and their potential for misconceptions (Chiu, et al., 2002).

Bouta and Paraskeva (2013) executed a mixed methods study to evaluate the potential of an online 3D virtual environment to teach fractional theory to 24 fifth graders and 19 sixth graders and in a Greek primary school. The socioeconomic status of the children was not given. The 3D program, called CoSy World, created a world for the students in which they had to use their knowledge of fractions to navigate (Bouta & Paraskeva, 2013). The world consists of two different locations, a travel agency and part of ancient Cairo. The children collaborated to solve fractional problems as they explored the ancient city of Cairo. The article includes excellent visuals both of the alignment of cognitive apprenticeship theory with the fractional concepts presented in the virtual world, and scenes of the virtual world itself. The program certainly seems like it would be appeal to children of different age groups (Bouta & Paraskeva, 2013).

Quantitative data were collected via pretests and posttests. The students had been exposed to fractional theory prior to being placed in this study. The study lasted two days. Each session lasted two hours. Qualitative data were collected via messages from on-line flow charts and analyzed using contextual coding. Statistical analysis was accomplished using Wilcoxon's non-parametrical criterion. The results of the posttest show an increase of almost 100% concept understanding for each fractional concept category presented for a two-day program. Personally, while this program appears to be an effective tool to teach fractional theory, one has to question such an increase of conceptual understanding in two days from 5^{th} and 6^{th} graders. This study should be repeated for verification.

Tsai, Jack, Huang, and Yang (2012) conducted a quasi-experimental study to determine whether or not a web-based cognitive apprenticeship software program used to teach scientific argumentation could successfully increase the skills of fifth-grade students in Taiwan. The ability to defend one's hypothesis logically in the scientific community is an important skill. It is very difficult for a teacher of 20-25 students to use cognitive apprenticeship properly due to the limited time per student. To compensate for this, a web-based system entitled 'Cognitive Apprenticeship Web-based Argumentation System' was used (Tsai, et al., 2012). Researchers hoped this approach would allow each student to receive the necessary feedback required plus ample collaborative interaction with both the teacher and their classmates.

One-hundred ninety-two students were divided into three groups; experimental group I, experimental group II, and the control group. All students were given a pretest to evaluate argumentative skills, and it was determined that the skill level differences between the students was not significant (Tasi, et al., 2012). Experimental group I had full access to the entire web-based software program, which included the entire array of modeling techniques used in cognitive apprenticeship theory plus the ability to see the work of all the other students in their group. Experimental II group could use the web-based system to construct their arguments, however, they did not have full access to all of the web-based tools nor could they view other students' work. The control was not allowed to use the web-based software program at all.

Results analyzed by ANOVA, revealed significant differences of gains in argumentation skills between the three groups. Experimental group I scored twice as high as experimental group II, and experimental group II scored twice as high as the control group. Researchers were well impressed with the results and plan to continue using the software (Tsai, et al., 2012). No flaws were found in this study other than one wonders if fifth-grade students could completely comprehend the significance of scientific argumentation and execute the skills.

Putica and Trivic (2016) examined the effects of the application of cognitive apprenticeship model in organic chemistry teaching in secondary schools. An experimental group of 118 students and a control group of 123 students were taught five periods of *Carboxylic Acid and Their Derivatives.* Both the experimental and control groups were divided up into five classes, which meant each class had approximately 25 students. The average age of the students was 17 (Putica & Trivic, 2016). The experimental group was taught with the cognitive apprenticeship model, and the control group was taught with traditional teaching methods. The first period students were given a pretest, the last period students were given a posttest, leaving three periods for actual instruction. The experimental group results were slightly higher than the control, however, the difference was not significant.

The lack of significant finding in this study is probably due to the fact that the classes were too large, and the period of time allocated to teaching carboxylic acids with the cognitive apprenticeship model was too short. Cognitive apprenticeship requires strict adherence to the principles and methods, plus sufficient time spent in small groups with the mentor and a program length of at least a few months.

The Waksman Student Scholars Programme (WSSP), based out of Rutgers University, uses a cognitive apprenticeship model to offer authentic science research and contextual enculturation to high school students (Charney, et al., 2007). In 2001, thirty high school students from fifteen different schools were chosen to participate in the summer program, which took place in July. The students attended the program five days a week from 8:45 am to 3:45 pm. There were also six follow-up meetings during the school year, plus poster presentation sessions (Charney, et al., 2007). Students had computer access to internet-based bioinformatics at all of their schools. Training seminars, open-ended question sessions and collaborative discussion were included. All of the students were “bright and motivated” (Charney, et al., 2007, p.200). There were slightly more females than males; ethnicities were Caucasian, East Indian, and Asian. All were from urban and suburban district of various socioeconomic status.

The goal of this program was to integrate aspects of scientific thinking into the students’ lives. Therefore, the students’ beliefs about the “nature of science” were measured. At the beginning and at the end of the summer, students were given a questionnaire and a checklist concerning their beliefs about science. Responses were coded as to the level of sophistication, level 1 being the simplest and level 4 being the most complex (Charney, et al., 2007). In addition, two AP biology essay questions were given to the students, and they were also required to keep journals. A similar, but different post-test was given at the end of the program. While all students took the pretest and posttest, only two of the journals and responses to the AP essay questions were evaluated. The pretest and posttest AP questions were graded by AP trained raters. Two of the raters were in agreement, the third one was not. The results showed significant gains in conceptual knowledge and gains in the sophistication of answers to the extended response AP questions for these two students (Charney, et al., 2007).

Based on this paper, the study has several areas of weakness. The paper did not go into specifics as to how cognitive apprenticeship methodology was implemented, whether or not the students had any choice in the projects, or if they were in control of their research questions. The program lasted four weeks. This is not enough time for students to be trained in authentic research and then proceed to do their own research. While it is apparent that all the journal and AP extended question entries were read, only the journals and extended AP questions of two students were evaluated. That was 6.7% of the sampling. The study brought light to the fact that there was not enough time to evaluate all of the results and conceded that this was a flaw in the study.

Collectively, the cognitive apprenticeship studies reviewed indicate that this methodology has potential to positively impact students' motivation, scientific reasoning and problem-solving skills, and STEM self-efficacy. Personally, I have used cognitive apprenticeship in my advanced biology classes for the last two years, and it has been very successful. Students have been able to publish their scientific research both years, and the majority of students in these classes have gone on to college and selected STEM majors. Cognitive apprenticeship provides a viable conceptual framework for implementing authentic research in the classroom. However, there have been far too few studies exploring students' perceptions of cognitive apprenticeship methods in science, especially high school science. Some of the research studies reviewed have been professionally executed. Several have flaws in their research design. The flaws identified were (a) inappropriate age level for subject material, (b) students did not have control over their research questions, (c) too short of time span allotted for the research, (d) insufficient data collection, (e) use of inappropriate research instruments, and (f) classes that were too large for the methodology.

My phenomenological study is designed to bring to light the impressions, feelings, and experiences of students participating in projects taught with cognitive apprenticeship methodology. The study will add to the existing research literature by documenting the students' impression of the impact of this authentic research on their lives and their perceptions of the impact it had. Commonalities and patterns found embedded in the students' descriptions of their experiences and feelings will be documented.

Chapter 3: Research Design

Solving the deficit problem of STEM majors in postsecondary institutions is vital to America's future. Today our country is depending on foreign-born STEM talent to fill many pertinent science and technology positions (National Science Board; 2015; Foundation, 2010; Presidents' Council of Advisors on Science and Technology, 2012). It is estimated that there will be 2.4 million STEM job openings by 2018 (Carnevale et al., 2014; National Science Board, 2010, 2015). The underrepresented segments of our population, women and minorities, are an untapped resource that must be utilized to fill this deficit (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2011; National Science Board, 2010, 2015; President's Council of Advisors on Science and Technology, 2012). Presently, the recruitment levels into STEM programs are stagnant, and the attrition rate of students leaving STEM majors is increasing (National Center for Education Statistics, 2014). The attrition rate for women and minorities is exceedingly high, and the recruitment rate is low. Three factors contributing to the low levels of recruitment and high level of attrition of underrepresented populations into STEM fields are (a) lack of authentic research experience often referred to as open inquiry (Committee on Science and Technology, 2007; Oriz & Srirman, 2015), (b) lack of high school preparation (Dika & D'Amico, 2016; Goldman, et al., 1976; Hackett & Betz, 1981; Sells, 1973), and (c) cultural differences between science and the students' social world (Aikenhead, 1996, 1998; Costa, 1995).

Cognitive apprenticeship (Collins et al., 1989), a social constructivist teaching methodology, is a conceptual framework for incorporating authentic research into the classroom. It uses techniques that address several reasons why women and minorities do not enter or leave STEM majors. Cognitive apprenticeship uses a "community of practice" (Lave & Wagner, 1991) where the teacher is the master scientist and the students are the apprentices. Scientific thinking, technical skills, and cognitive skills are taught through modeling, coaching, scaffolding, articulation, reflection, and exploration (Collins et al., 1989).

The purpose of this phenomenological research study (Moustakas, 1994) was to describe former students' lived experiences who participated in high school science projects taught with cognitive apprenticeship methods (Collins et al., 1989) and also to record their impressions of how the projects were facilitated, how the projects impacted their success or lack of success in university, and how these experiences impacted their choice of major in university or their selection of a job in the work force. Studies were found documenting teachers' impressions of using cognitive apprenticeship as a viable method for teaching science, however, no studies were found that recorded the students' impressions of the method. Beings the students are the main focus of the STEM deficit, it is imperative to know exactly how the method affected them. It is the students who are not be recruited or leave STEM majors, not the teachers. In the following sections, I will describe the study design, data collection procedures, data analysis, and trustworthiness and reliability.

Ethical Considerations

Permission was obtained by the University of Oklahoma's Institutional Review Board (OU-IRB) to protect the rights of the human participants (see Appendix A) before proceeding with the study. An application for expedited approval was completed which included recruiting up to 7 participants between 18 and 20 years of age who had been taught with cognitive apprenticeship methods on one or both of the projects. Students were not chosen due to their ethnicity, race or gender. The application documents included an informed consent form (see Appendix B) to be signed by the participants, recruitment guidance, a sample of the questioning strategy, and proper protocol for completing the investigation. All participants of the study were informed of the rights, and that they had no obligation to consent. All signed consent forms were duplicated; one copy was kept by the investigator and one copy was given to the participant. The study was approved on December 19, 2017. For the duration of the study, all measures and guidelines were followed, including securing all forms, documents, and audio tapes.

Setting

Whitesworth, a pseudonym, has a population of 505 people and is located in a remote, rural area of a southeastern Oklahoma county. It has a poverty rate of 27.5 % (U. S. Census Bureau, 2013). The high school serving this town and surrounding areas has 90 students. One hundred percent of the students qualify for free lunches. Thirty-one percent of the students are on Individual Educational Plans (IEP) (A. Johnson, personal communication, December, 2017). The students' results on the state's "end of the year" assessments and the ACT assessment are below state averages (Oklahoma State Department of Education, 2016). In 2017, most of the students had a composite ACT score between 14 and 17 out of 36; the highest score in the school was 24 (A. Johnson, personal communication, December, 2017). Additionally, very few students who choose to pursue the military by taking the Armed Services Vocational Aptitude

Battery (ASVAB) (U. S. Department of Defense, 2014) qualify to enter the military (P. Hall, personal communication, December, 2017).

After graduating from high school, only a small number of students obtain gainful employment and most work for minimum wage. A small number of students attend college and fewer graduate from college. Since 2010, three students from Whitesworth High School have graduated from college, and only ten to fifteen are still actively enrolled in an undergraduate program. The average graduating class has approximately 30 to 35 students. In 2017, there were 51 students in the graduating class; only seven were accepted to four-year institutions. Of those seven, only four had skills levels conducive to entering college without taking remedial classes.

As the only biology teacher in the school, I have taught all of these students and know their skill level. Three of the four students with appropriate skill levels have spent 1.5 years in the cognitive apprenticeship program in the school and subsequently declared as STEM majors (biology, marine biology and computer engineering). The majority of Whitesworth High School students have below average academic skills. Most of the students that have average to above average academic skills do not apply to colleges and/or universities for four-year degree programs.

Participants

I utilized purposeful sampling for this phenomenological study to identify individuals according to the following criteria: participation in the Rhizobia Project and/or the *Wolbachia* Project using cognitive apprenticeship methodology and graduation from high school. Twelve former students who met the selection criteria and whose contact information could be located were contacted via telephone and asked to participate in the study following the approved recruitment protocol. Six former students consented and agreed to participate in the study.

Phenomenon

The experience in this phenomenological research study (Moustakas, 1994) is participation in high school science projects following cognitive apprenticeship methodology (Collins et al., 1989). Cognitive apprenticeship incorporates the culture, specific techniques and skills, and the cognitive processes of a discipline. In this case, it specifically uses the culture, techniques, skills and cognitive processes of science. The culture of science includes an open exchange of ideas, problem solving techniques, and probing questions. Cognitive skills are used to formulate the research question, design the research, and collect and analyze the data. The essence of this program is a "community of practice" established through master apprenticeship relationships (Collins et al., 1989). The master of the discipline, the teacher, is required to have domain knowledge plus heuristic, control, and learning strategies of a particular discipline. This knowledge is constructed by apprentices through modeling, coaching, scaffolding, articulation, reflection and exploration (Collins et al., 1991a). Students work together socially to create knowledge to learn increasingly difficult skills. Mental processes, such as problem solving and scientific thinking, are expressed verbally.

As mentioned earlier, this research is a phenomenological study. The study has documented the lived experiences and feelings of former students who participated in one or both of the two high school science projects taught with cognitive apprenticeship methodology.

The Rhizobia Project took place during the 2013-14 school year. This project was not associated with a class. The students worked one weekend per month at a large university’s research laboratory and weekdays during study hall at the high school. During the first session at the university, the students took a safety course and collaborated with me and the department chair to formulate a research question and method protocols. The focus of the research was to see if there was a correlation between the amount of water given each *Glycine max* (soybean) plant and the rhizobia nodulation rates of two wild strains of rhizobia. The two strains, TXVA and TXEA, were isolated in a drought area of northwest Texas and were thought to be drought resistant. The responsibility for the strains was divided between the students. The students and I traveled to the university to make new agar plates, re-plate the rhizobia, make the rhizobia inoculant, and destroy the old plates. The rhizobia inoculant was transported following safety protocols to the high school where the plants were inoculated four weeks after germination. Three generations of plants were grown that year. While at the university the students were taught these skills through modeling, coaching, and scaffolding. After the skill was modeled, the students would try to duplicate the process. In addition to my comments and instructions, they also helped each other. During the drive home, which took 1.5 hours, the students would articulate the information they had learned. While at school, plant growth rates, the amount of water given to the plants, the nodulation rates, and the production of biomass were recorded. The students also helped analyze some of the data. The final data analysis was done by the department head and incorporated into an article for publication. Afterwards the students were asked to reflect on their experiences.

The *Wolbachia* Project took place during the spring semester of 2016. The research focused on *Wolbachia* infestation of insects in the local area. *Wolbachia*, a Gram-negative Rickettsia bacteria inhibits a mosquito's ability to transmit many dangerous human pathogens, but it also has detrimental effects on insect propagation. To determine insect infestation, DNA is extracted using a 24-step process. The DNA is then amplified with PCR, run through electrophoresis, and viewed on a DNA illuminator. Using the restriction enzyme TERnase, *Wolbachia* DNA is 438 kilobase pair (kbp) and insect DNA is 709 kbp. To learn the technical skills for this research, students first attended a workshop at a central Oklahoma university where the professor and I modeled the skills, and then the students would try to duplicate them. Students were guided by coaching and scaffolding. Afterwards, technical skills were reviewed several times using the same methods. Cognitive skills and strategies required to read and evaluate scientific publications, analyze data, resolve problems, and write a publishable scientific manuscript were taught during class using the same methods. To ensure that students were motivated by the open inquiry process and not grades, all of the students knew beforehand that they would receive an A for the course. The artifacts and research question were decided upon collaboratively by the students. The research resulted in a manuscript published in the *National High School Journal of Science* (see Appendix D).

Epoché

To help me evaluate interviews objectively, Moustakas (1994) suggested that the researcher experience the process of Epoché by viewing the phenomenon with "fresh eyes". In this way, phenomenological research is transcendental. Experiences must be viewed without any preconceived ideas or opinions. The phenomenon in question is cognitive apprenticeship. In order to be completely objective, it is important for me to remember how I came to embrace cognitive apprenticeship.

I have always loved science. Growing up in the post WWII era, science was king. Many movies and television shows of the day emphasized the stimulating and noble world of science. Science was going to create a better world for tomorrow. I wanted to be part of that world. In elementary school, I read every book I could find about science and scientists. I fell in love with biology. In the fifth grade I decided that I would become a microbiologist, go to Africa and work with Dr. Albert Schweitzer. My parents were horrified. Earlier when I had asked for chemistry sets or a microscope for Christmas, my parents thought it was cute. However, when I declared that I wanted to devote my life to science, it was not cute. Women that went into science were not socially acceptable. Of course, my parents thought they were guiding me to a more acceptable and happier life. Studying microbiology and going to Africa were not going to be in my future, for a while.

After graduating from college with a degree in elementary education, I was determined to energize my students and instill in them a love of inquiry and science. Also, by preparing lessons for them, I was learning too. I studied different aspects of science every day, trying to make the lessons more challenging and interesting to the students. Slowly I worked my way up from teaching elementary school to teaching International Baccalaureate Higher Level Biology in Egypt and Saudi Arabia. After retiring and moving back to the United States, I decided to renew my dream of becoming a microbiologist. I earned a master’s degree in plant and soil microbiology from a large research university in central Texas. Upon the completion of the master's degree, I set my sights on earning a Ph.D. in plant pathology. However, being a woman was no longer an obstacle to achieving my dream, but my age was the issue. Plant pathology departments wanted young, super students who had a long career of publishing and networking ahead of them. Of course, age discrimination is against the law, but "off the record" I was told I was too old for their programs. Since most of my career has been in education, I decided to apply to the University of Oklahoma for a Ph.D. program in instructional leadership and was accepted. About the same time, I obtained a teaching position a small remote, rural high school in southeastern Oklahoma. Teaching these students was going to become the biggest challenge of my life. The students had been exposed to textbooks and worksheets for their entire educational career. They lacked interest, skills, motivation, curiosity and rigor.

The first few years, I used the "IVP" or inform, verify, and practice method. This was definitely better than textbooks and worksheets, but I felt there had to be something better. And besides, I was bored. I felt if I was bored they had to be also. At the same time, the large research university where I had recently earned a Master of Science degree hired me to maintain their microbial cultures, which included different strains of rhizobia and *Phytophthora*. I would drive down to the university on the weekends to maintain the cultures. I asked the department head if I could bring a small group of students with me to teach them different microbiology techniques. This idea was approved; the students had to take a safety course, consent and assent forms were signed, and the students were never to be left alone while at the university. Then, the department head and I came up with the idea of including the students in an authentic research project. We named the project, “The Rhizobia Project”. Though I did not realize it at the time, I was using cognitive apprenticeship methods for the project. This project lasted one academic year. I was so impressed with the students. They were taking their free time to come with me to pursue science. In reflection, this statement is important. There has to be an ember or glow of perseverance and motivation in the students initially before one can help them to launch into a career of science or mathematics. One cannot fan flames from a dead ember; it must be glowing before one can add oxygen and ignite the flames.

Two years ago, my advanced biology class was flat. There was no interest or enthusiasm. I desperately went looking for a teaching method that would stimulate both my students and myself. I remembered the Rhizobia Project. In the literature, I found several research papers detailing a method from the late 1980’s called cognitive apprenticeship. This method of teaching aligned exactly with the way I taught the Rhizobia Project. Cognitive apprenticeship was advocated as a conceptual framework for project-based learning. One day, I just asked the students if they would like to participate in a project based on using cognitive apprenticeship. Of course, I had to sit down and explain both concepts to them. The vote was an overwhelming “yes”. Anything had to be better than what we were doing!

I had heard about a bacterium that was infecting insects from a biotechnology professor at a central Oklahoma college. Through communication, the professor and I decided to provide a workshop for the students on *Wolbachia*, the bacterium. The protocols to isolate and identify it were quite extensive. Everyone was energized!

After the workshop, the students and I sat down together and discussed responsibilities, time limit problems, protocols, plus the artifacts or end products of this project. The students decided on three artifacts, (a) a YouTube explaining their research, (b) a presentation on their research to the molecular botanist that visited us once a year, and (c) to publish a manuscript in the *National Journal of High School Science*. In hindsight this was too much work for one semester. To make a long story short, we went through a series of trials and tribulations. The most arduous part of the project was not the research but writing the manuscript and preparing for the presentation. The students had no idea how to prepare for a scientific presentation. The majority of the students had never before seen a published scientific manuscript. Understanding the information was a daunting event for them. Slowly, everyone's reading, writing and presentation skills improved. We successfully completed the manuscript and the presentation. With these events behind us, creating the YouTube video was easy. The manuscript was published, and we were all very proud of ourselves.

My experience in cognitive apprenticeship methodology was an eye opener. I knew the students had limited skills, self-efficacy, and perseverance, but I did not understand how limited. This method of teaching not only gave me the opportunity to learn biological techniques and theory, it gave me the opportunity to increase my delivery of the elements of cognitive apprenticeship. I had used these elements before in the Rhizobia Project even though I did not realize I was using the cognitive apprenticeship method. Cognitive apprenticeship was not only beneficial for my students, it was beneficial for me as well. In this project, we were a team of scientists collaborating, supporting each other to reach a desired goal. I was learning right along with the students. It was my dream come true. We were research scientists. I also came to the realization that cognitive apprenticeship requires an extreme amount of patience, energy, technical equipment, organization, and education on the part of the teacher. Since, I had two master's degrees, education was not an issue. The most difficult part was relinquishing control of the project to the students. I was a senior member of the team, but just one member. Personally, I believe relinquishing control is the issue that most teachers would find repugnant. Even though the teacher is the master scientist in cognitive apprenticeship, the students are in control of their research.

Problems always arise in research. Our techniques for solving problems, including differences of opinions within the team, became increasingly more sophisticated. At the end of the semester, we discussed the program and its effect on all of us. The entire team believed their confidence, science self-efficacy, collaborative skills, scientific skills and motivation increased. This phenomenological study documents the experiences and feelings of the students who participated in either the Rhizobia Project, the *Wolbachia* Project, or both projects.

Data Collection/Procedures

Qualitative data were collected using semi-structured interviews with open-ended questions. Questions were organized in clusters to facilitate detailed participant descriptions rather than a one question/one answer dialog (see Appendix C).
All interviews were audio recorded using my smart phone. Five, face-to-face, one-on-one interviews took place in my home office between December 27, 2017 and December 30, 2017. Two session times (10:00am and 2:00pm) from which to choose

were available for the students. The majority of the interviews lasted between 30 and 35 minutes, while one interview lasted 50 minutes. The sixth interview was conducted via Skype and lasted 31 minutes. All interviews were transcribed non-verbatim by the researcher. To ensure confidentiality and anonymity, all data were securely stored in the researcher's home safe and individual pseudonyms were provided for each participant. All data were deleted at the conclusion of this study.

Data Analysis

As part of phenomenological research, data analysis followed the steps as outlined by Moustakas (1994). These steps are Epoché, phenomenological reduction, imaginative variation, and synthesis. These steps will be described in the following sections.

Epoché.

As previously described, I participated in the process of Epoché where I attempted to set aside my biases and prejudgments so that I could begin solely focusing on the participants' experiences with the phenomenon to later describe the essence of these experience with the phenomenon (Moustakas, 1994).

Phenomenological Reduction.

I began phenomenological reduction by 'bracketing' the topics that referred to the research question. To do this I located key phrases in the interview that were directly related to the research questions (Moustakas, 1994). Then as an informed reader, I interpreted the meaning of the phrases the phrases or statements both in isolation of the text, and also in context to understand the participant’s meaning

(Creswell, 1998). I then read and reread each interview transcript identifying significant statements that revealed how each participant experienced the phenomenon.

For example, the overarching research question was: what were the lived experiences of students who participated in authentic research that was guided by cognitive apprenticeship methodology? In John's interview about the *Wolbachia* Project he stated, "[Reading these papers was definitely a challenge]". The sentence refers to part of the experiences John remembered from the project, therefore it was bracketed and became a significant statement.

I looked for reoccurring phrases or ideas in the interviews. This process is referred to horizontalization where each individual statement for each participant is treated as having equal worth (Creswell, 2013; Moustakas, 1994). To clarify this process, Victoria stated, "[We used published research papers to get information about *Wolbachia*. The terminology was difficult. The papers were written on a high level and were more difficult to understand]". This statement reflects Victoria's memory of her lived experience in the project and was therefore bracketed. Both of the statements from John and Victoria refer to their memory of reading and understanding the scientific research papers. Therefore, in horizontalization these two statements were aligned. This process was repeated throughout all of the interviews to identify themes or meaning units. Professional papers became one of the meaning units. Redundant and irrelevant statements were removed. Identification of the meaning units facilitated individual textural descriptions of each participant followed by combining the individual descriptions into a composite (or group) textural description. For the purpose of this study, textural descriptions focused on the "what" the experiences of each participant was regarding cognitive apprenticeship method within the context of participating in one or both of the science projects. Structural referred to “how” it was done (Creswell, 2013; Moustakes, 1994).

In Mary’s interview regarding the Rhizobia Project, two of her significant statements were, “We also learned how to transfer bacteria”. That was a textural description of “what” was done. “The teacher would first show us how to do it then she would watch us as we repeated the skill”. That statement is structural because it refers to “how” it was done. This process was also repeated throughout the interviews.

Imaginative Variation.

Following the generation of a composite textural description of the participant group, I utilized imaginative variation, which required me to approach the phenomenon from different perspectives and viewpoints of each participant. Undertaking this step of the data analysis process allowed me to develop the structural description, or "how" the students experienced cognitive apprenticeship (Moustakas, 1994).

As the master scientists in this “community of practice”, I decided that our team interactions would be positive, supportive and encouraging. This philosophy was stated at the beginning of the projects. For imaginative variation I approached the phenomenon from a different viewpoint, one where a positive philosophy of interactions was not stated. No philosophy was identified, not positive, neutral or negative. The philosophy was absent.

Synthesis.

The final step of phenomenological data analysis that I followed was the synthesis of the composite textural and composite structural descriptions necessary to answer my research questions by describing the essences of the phenomenon under study (Creswell, 2013; Moustakas, 1994). Textual and structural descriptions from all of the interviews were interwoven to reflect the synthesis of the experience. An example of synthesis of the Rhizobia Project is given below.

The Rhizobia Project.

The students' initial exposure to open-inquiry research, the Rhizobia Project, was positive and without pressure. It was the first time they had been to a university research lab. "We had to go to the university to work" (Victoria). "I really looked forward to these trips. But some of the other students felt intimidated" (John). "Also, that was my first experience with a university lab. I was in awe!" (Victoria). Both John and Mary remembered taking a safety course before the university would allow them to work in the lab, but Victoria did not mention it. Victoria and Mary felt timid about working in the lab. "It was intimidating at first because there was so much we did not know. I remember being quite nervous most of the time" (Victoria). "We were all pretty hesitant about working in the lab. I remember being very anxious and really down right scared going to the university. Slowly we began to be comfortable working with the equipment and being in the lab" (Mary).

This procedure was continued throughout both projects.

Trustworthiness and Reliability

Reliability is defined as the extent that the results accurately represent the population being studied (Golafshani, 2003). Considerable measures were employed to establish that the findings were reliable. This research also follows Morrows (2005) recommendation for conducting trustworthy qualitative research (Morrow, 2005). The research strictly adhered to phenomenological research methods including data collection and data analysis as described by Creswell (2013) and Moustakes (1940).

Multiple procedures were used to ensure the results of this phenomenological study were valid. The interviews were private and recorded on a smart phone. Prior to the interviews, participants were instructed their responses should be free of bias. Questions were clustered to encourage rich, thick descriptions by the participants as opposed to a question/ answer scenario. Interviews were transcribed that evening. The transcriptions were validated three times by comparing the text to the audio recording. Afterwards, transcriptions were member-checked by the participants. All statements, whether positive or negative, were used in this study. During of the process of clustering to identify meaning units, original statements were not edited in anyway.

Chapter 4: Findings

Both science projects, Rhizobia and *Wolbachia*, included significant technical and cognitive skills. The Rhizobia Project had no pre-requisites other than an interest in biology. Any student between the 8th and 12th grades willing to work on the weekends and during study hall could join. The only pre-requisite for the *Wolbachia* Project was to have taken Biology I and be enrolled in Biology II.

The overarching question of this study was: what were the lived experiences of students who participated in authentic research that was guided by cognitive apprenticeship methodology? In addition, the following sub-questions further guided the research on this topic:

1. What were the impressions, feelings, and perceptions of these students while participating in the projects?
2. What commonalities or patterns were found in these experiences?
3. How did the students' experiences influence their lives, especially in their choices to pursue post-secondary education?

Phenomenological Reduction

The interviews were divided into two or three sections depending on whether the individuals participated in one or both of the projects. The first cluster of questions pertained to the students' present situation. Responses were used to write the narrative descriptions. The narrative for each student includes information on their present status, their scientific interests, if they are attending a university or not, if they felt prepared for the university classes, and if they had obtained any scholarships. This information was pertinent due to the fact that their participation in these projects may have impacted their science self-efficacy, skills, and success or lack of success in their college classwork, research, or employment. The interviews covered their experiences while participating in the projects, and their feelings, perceptions, and impressions about those experiences. These interviews were included in the dissertation to allow the readers to view the participants' dialogues with "fresh eyes" and to validate the analysis of the researcher. It also allows the reader an enhanced opportunity to understand the participants and the emotional dialogue of the interviews. Brackets were used to identify significant statements that would later be used in identifying themes or meaning units.

John.

Narrative Description.

John graduated from Whitesworth High School in May 2017 and is presently in his second semester at a university and is majoring in computer science. He plans on staying at there unless it becomes too expensive for him. He has several scholarships: the Heritage Scholarship, the University Scholarship, and the Carolyn Watson Foundation Scholarship from the Oklahoma City Community Foundation. John believes he will have these scholarships for four years if he re-applies for them each year and keeps his grade point average (GPA) above 3.0. Last semester, he earned a 3.4 GPA. John intends on looking for more scholarships while he is on semester break.

Last semester, John took two science courses, chemistry and the freshman engineering experience. John has always loved science and felt very prepared for his courses. He was extremely pleased with the engineering course but not with the chemistry course. John felt the professor was disorganized, and the information in her lectures did not always align with the information on her Power Point presentations. However, the labs were run by a teaching assistant (TA) who did a wonderful job and was always there to help any student with problems. John thought the labs were pretty easy. He claimed that his lab partner stated many times how helpful John was to him, because of all of John's lab experience. The engineering course did not require any prior knowledge; some students come to university with programming experience, but not many. John had originally planned on going into aerospace engineering, but he changed his mind in high school. As for his public school education, he did not remember having any labs in his elementary or middle school classes. All of his lab experiences were in high school.

Rhizobia Project.

I was in the eighth grade for the Rhizobia Project. [Each of us that participated had our own separate pot with a soybean plant in it]. Then what we did throughout the year was to water it, set it out in the sunlight for a while, and then would have to watch if any clippings came off like leaves or stems. And we would have to keep them. [We kept track of all the growth measurements in our journals], and we would have to keep any of the droppings in a bag so [we could measure the biomass of it at a later time]. So, throughout the semester we would just record the changes in growth, how much water we gave to the plants, and when we put the plants in the sunlight and took it out again. At the end of the study, [we counted the number and size of nodules on our plants].

[We had to take a safety course] before we could work in the university lab. We had about 6 students in the Rhizobia Project. At the university [we would go over procedures such as transferring bacteria], and just different methods going through our [procedures for caring for the plants and cultivating the bacteria]. We didn't have access to everything that would have been necessary like the autoclave or at that time and we did not have a hood which you need for transferring the bacteria. [We went to the university on weekends]. Our teacher would set up certain dates and ask us beforehand if we wanted to go. [I really looked forward to these trips]. It was great going and seeing what it was like there. I believe I had been to a university before, but [never had the opportunity to work in a university lab]. I can't remember much about the professors either because it was so long ago, but I am sure they were really nice to all of us. [It was a new experience for all of us]. All of the students going to the university got along and [helped each other]. [I think this experience helped us to realize what college would be like and made us feel more comfortable]. [I did not feel intimidated about going to the university] and working in the lab, but [some of the other students felt intimidated]. All of the data obtained from this project was given to a professor who published an article on the results.

Significant Statements: Rhizobia Project.

- "We all had our own separate pot with a soybean in it".
- "We kept track of all the growth measurement in our journals".
- "We measured the biomass of it at a later time".
- "We counted the number and size of nodules on our plants".
- "We had to take a safety course".
- "We learned procedures for transferring bacteria".
- "We learned procedures for caring for the plants and cultivating the bacteria".
- "We went to the university on weekends".
- "I really looked forward to these trips".
- "I had never had the opportunity to work in a university lab".
- "It was a new experience for all of us".
- "We helped each other".
- "We realized what college would be like and made us feel more comfortable".
- "I did not feel intimidated about going to the university but some to the other students were intimidated".

Wolbachia Project.

In the *Wolbachia* Project, [we would have to extract DNA from the insects found at our school's location to try to find out which insects were infected with *Wolbachia]*. *Wolbachia* is a Gram-negative bacteria which affects the reproduction of the insects, but it also has positive affects for humans like preventing the transmission of potentially dangerous diseases like the Zika virus.

[We learned a lot of skills including using the micropipettes, the mini-PCR, and the electrophoresis chamber]. [We had to learn how to make agarose gels, how to load the dye into the DNA we had extracted and go through the process of making sure our DNA was not contaminated]. [We had to learn to keep everything organized, and how to work the centrifuge]. We [learned these skills through demonstrations from our teacher] plus we also made a trip to another university and went through a workshop to learn how to extract DNA and screen for *Wolbachia*. [The methods were demonstrated, and then we were guided through the process until we could do them without supervision]. [There were no tests or quizzes]. The closest thing to a quiz was [our teacher asking about what we were doing] to make sure we knew what we were doing. This usually happened during out lab meetings. [For about 10 minutes we were "grilled" on procedures and content knowledge].

Learning to use the equipment did not feel like as much as a challenge as I thought it would have been. [After I did learn how to use all the equipment, I realized that learning to do other procedures in college would not be as difficult as I thought it would be]. Especially in programs like engineering.

The [procedures used to teach this project were much better than the procedures used to teach the other classes] I took in high school. [This was more of a “hands-on” project]. Also [the critical thinking our teacher put us through really helped], for example [she made us solve our own problems] instead of just giving us the answers. So, throughout the project anytime we came up with a problem such as a data error we would have to go through and find it. [She would guide us but not give us the answers]. [We would have to find all of our errors] ourselves. We had a large amount of data because we had over 100 insects.

Well a lot of time we had to figure out what the problem was on our own. [We had to find information by reading the research materials] we were given. We had to find information that would help us write the background for our paper and compare different results. We were using different professional published papers that were related to our field of research. [Reading these papers was definitely a challenge]. You had to find out how to relate everything, but nothing is exactly like your project. [Some of the other students really struggled with reading and understanding the papers]. We would help each other, and also [our teacher gave us different strategies to work through the papers]. We had some problems come up such as our agarose gels breaking, problems with the bands on our agarose gels not showing up well. [We also had some organizational problems]. [One time our samples fell out of the freezer and got mixed up, so we had no idea of what was what anymore. We learned more from situations like that then we could have from studying a textbook].

There were 7 or 8 students in the *Wolbachia* group, and I think we all pretty much got along. Every once in a while, we would have minor differences, but pretty much we all got along. The [end products of this project would have been the paper we had to write]. We had to organize our results into a paper that would be submitted for publication. [Writing the paper was definitely a challenge]. [The experience really prepared us for college]. I never really got frustrated with the experience. Oh! We also had to make a You Tube on our research and presented our information to a university professor that came to work with us once a year.

For some of us, [we really had no experience presenting information] in front of a crowd. Some of us were pretty shy to talk in front of people and a camera. I feel [I learned more from this project than I would have learned from a regular class]. [It definitely feels it prepared us more for college] than other classes. Maybe not so much for general education classes, but definitely for advanced classes where you have to write strong papers. Another problem with regular high school classes, is they slow down for the slower students. But at university, they do not slow down! So, you are not really preparing your students for that.

[Towards the beginning of the project, most of us felt like publishing a paper was completely out of our reach]. But as we were going through the project and actually getting results, [we began to feel that it was actually something that was doable]. [We all felt that it was a great accomplishment to publish a paper while we were still in high school].

[For the *Wolbachia* Project, there were really no grades. Everyone just got an A. The point being was to eliminate studying for a grade and not studying for the knowledge]. [Not having to worry about a grade relieved a lot of stress. Because whenever you start worrying about grades you feel like you're not going to get something done]; [some students really start to stress out and their work efficiency suffers. They will not produce as good of results]. It just does not help anyone, especially in a project like this. Personally [I never get stressed about anything]. I just keep studying.

Significant Statements: Wolbachia Project.

- "We extracted DNA".
- "We used micro-pipettes, mini-PCR, and electrophoresis chamber".
- "We learned how to make agarose gel, how to load the dye into the DNA without contamination".
- "We had to learn to keep everything organized".
- "We learned these skills through demonstrations from our teacher".
- "The methods were demonstrated, and we were guided through the process until we could do them without supervision".
- "There were no tests or quizzes".
- "Our teacher would ask us what we were doing".
- "We were grilled on content and procedure knowledge during lab meetings".
- "I did learn how to use all of the equipment".
- "I realized that learning to do other procedures in college would not be as difficult".
- "The teaching procedures used in this project were much better than the ones used in other classes".
- "This was a hands-on project".
- "The critical thinking our teacher put us through helped".
- "She made us solve our own problems".
- "She would guide us".
- "We would have to find all our errors".
- "We had a large amount of data".
- "We used different professional published papers to obtain information".
- "Reading these [professional] papers was definitely a challenge".
- "Our teacher gave us different strategies to solve problems".
- "We had some organization problems".
- "One time our samples fell out of the freezer and got mixed up, so we had no idea of what was what anymore. We learned more from situations like that then we could have from studying a textbook".
- "We learned more from solving our own problems than we could have learned from a textbook".

- “Writing the paper was definitely a challenge”.
- “The experience really prepared us for college”.
- “We presented our information to a university professor came and worked with us once a year”.
- “We really had no experience presenting information before”.
- “I learned more from this project than I would have learned from a regular class”.
- “I definitely feel it prepared us more for college than other classes”.
- “At the beginning of the project, most of us felt like publishing a paper was completely out of our reach”.
- “We began to feel that it was actually something that was doable”.
- “We all felt that it was a great accomplishment to publish a paper while we were still in high school”.
- “For the *Wolbachia* Project, there were really no grades. Everyone just got an A. The point being was to eliminate studying for a grade and not studying for the knowledge”.
- “Not having to worry about a grade relieved a lot of stress”.
- “Some students really start to stress out and their work efficiency suffers”.
- “I never get stressed about anything”.

Mary.

Narrative Description.

Mary graduated from Whitesworth High School in May, 2016 and is now at a university majoring in Biology. She is taking her basic courses there, and then intends on moving to Galveston to major in Marine Biology. She had two scholarships upon entering the university, one for a semester and the other one is for four years. Mary felt very prepared for her science courses. She was in a biology course for majors and found it very simple and the laboratory exercises were quite childish. During the second semester of biology the students worked with transgenic bacteria which was interesting. Chemistry was easy as well. Mary took concurrent English in high school, and since then has not taken any English classes. However, she really struggled in math. Mary had been the valedictorian of her class and had taken algebra I, II, pre-calculus, geometry and trigonometry in high school. So, she thought she was well prepared for math, but she really struggled. Mary has to work to help pay for university expenses. She works at a casino and makes $ 4.00 an hour plus tips. She hates her job and plans to start applying for jobs at different banks. She believes they pay $ 10.00 an hour.

Mary has always loved science. When she was 3 or 4 years old her mother took her to an aquarium, and she knew right away that she wanted to work with sea animals. She had an excellent high school science program, but not so much in elementary and middle school. Most of her classes were based on textbooks and worksheets. The goal of most of her classes was to pass a test.

Rhizobia Project.

Well, the Rhizobia Project was a while ago. I was in the ninth grade then, so it was about 5 years ago. I remember that [we took monthly trips to a university] and [worked in the research lab down there learning how to prepare slides and plates]. [We also learned how to transfer bacteria] from one plate to another without contamination. [We had to be so particular]. [We were taught to try to be as perfect as possible]. [I learned how to use the micropipette and make agar]. [It was a lot of comprehensive "hands-on" work]. And, also every day in school during study hall, we had to take care of our plants. [They only received an exact amount of water]. I do not remember how much though. Oh! I also remember that a professor would come once a year and teach us about PCR.

I remember some of my feelings going to the university to work as a ninth grader. Well, [at first, I was very anxious and really down right scared]. There were so many things that I had not been introduced to. [But, I slowly began to be comfortable working with the equipment and being in the lab]. At first, [the teacher would first show us how to do it, then she would watch us as we repeated the skill]. If we forgot something, [she would help us through it until we were finally able to do it on our own]. [It made me feel very good about myself].

The project was pretty small. We started out with four, and then two more students were added to make six. [We were all pretty hesitant about working in the lab because we had never been to a university before], but [we became more and more relaxed in the lab]. [We would all help and encourage each other], which was nice. [We became a team]. The [rhizobia experience actually helped me during my first year at college]. [I felt more confident and comfortable than many of the other students with using the equipment]. In my second semester, [I was quite a bit ahead of the other students in terms of working with the equipment].

Again, [at first when the Rhizobia Project first started, I was really nervous]. I was not sure it was really what I wanted to do. [It was more in-depth than any of the science I had experienced]. The equipment looked so expensive. But [after a few months, the procedures became routine] and I was able to learn so much. Oh! I remember that [the university made us take a safety course] before we were allowed to work in the lab. And, always our teacher was with us. It would be nice if other schools would have projects like this one. [It prepared me so much]. Also, [I think there would be more students majoring in the sciences if all schools had projects like this one].

The other students in my college biology classes wanted to know how I knew so much about the equipment and bacteria. I know [for me, it was a turning point. This experience helped re-assure me that I could be successful in marine biology].

We never used books to learn. It was very different than anything I had experienced. [Our teacher would first explain what skills we would be learning, then she would do it herself]. Afterwards, [we would copy what she did]. [She would watch us and help us] if we were doing it incorrectly. [There was never anything negative, only positive encouragement]. [We also had our peers to help us]. I remember my best friend and I working together. Amy would give me pointers and I would help her also.

Another thing that helped me, was the visits by a professor. He would come down and bring equipment and work with us all day. I had never had that kind of contact with a college professor. It made me feel more comfortable about going to college. He was so nice. When our teacher told us he was coming, we were pretty scared. Then when he showed up, and began joking around with us, we all felt better. We were really intimidated at first, but he really helped us throughout that day. His accent was hard to understand at first.

[Our trips to the university were on Friday], a non-school day for us. The only time we worked during school, was when the professor would come down, and when were took care of our soybeans. The goal of the Rhizobia Project was to see [how many nodules the different rhizobia would form on the plant roots]. We could count and weigh the nodules.

Significant Statements: Rhizobia Project

- "We took monthly trips to a university".
- "We worked in the research lab".
- "We learned how to prepare slides and plates".
- "We also learned how to transfer bacteria".
- "We had to be so particular".
- "We were taught to try to be as perfect as possible".
- "We learned how to use the micropipette and make agar".
- "It was a lot of comprehensive hands-on work".
- "The plants received an exact amount of water".

- “I remember being very anxious and really down right scared going to the university”.
- “Slowly we began to be comfortable working with the equipment”.
- “The teacher would first show us first how to do it then she would watch us as we repeated the skill”.
- “She would help us through it until we were finally able to do it on our own”.
- “It made me feel good about myself”.
- “We were all pretty hesitant about working in the lab”
- “We had never been to a university before”
- “We became more and more relaxed in the lab”.
- “We would all help and encourage each other”.
- “We became a team”.
- “The rhizobia experience actually helped me during my first year at college”.
- “I felt more confident and comfortable than many of the other students with using the equipment”.
- “I was quite a bit ahead of the other students”.
- “It was more in-depth than any of the science I had experienced”.
- “The procedures became routine”.
- “I was able to learn so much”.
- “We took a safety course”
- “For me, it was a turning point”.
- “This experience helped reassure me that I could be successful in marine biology”.
- “Our teacher would first explain the skills, then she would do it herself”.
- “Then we would copy her”.
- “There was never anything negative, only positive encouragement”.
- “Our trips to the university were on Fridays, a non-school day for us”.
- “I think there would be more students majoring in the sciences if all schools had projects like this one”.
- “Our peers helped us”.
- “Prepared me so much”.
- “Goal of the Rhizobia Project was to see how many nodules the different rhizobia would form on the plant roots”.

Victoria.

Narrative Description.

Victoria graduated from Whitesworth High School in May 2017 and is attending the honors college at a university. Presently, she is majoring in biology and minoring in chemistry. Victoria entered university as a mathematics major, but after struggling in her two mathematics courses she switched to biology and chemistry. Victoria received the university's honor scholarship, which covers a large portion of her tuition, and some small scholarships as well from competing in curriculum contests. The scholarships covered about half of her expenses. Victoria felt very prepared for her biology class and felt decently prepared for her writing class. She was not well prepared for her calculus course. She had taken AP Calculus at a Kiamichi Technical Center (KTC) but did not take the AP test because KTC failed to tell her she had to register for the test. But in hindsight, she was glad she did not take the test because if she had passed it, the university would have enrolled her in Calculus II which would have been worse. Victoria works everyday as a math tutor and sees the irony in the situation. She mentioned that the university does not screen the students they hire to be tutors.

This semester she took Calculus I, a College Success Class for Honors, Technology in Mathematics, and biology. Victoria thinks she could have been successful in mathematics; however, she was so far behind the other students that catching up would have taken all of her free time, and she would not have any social life at all. Victoria did not regret her decision to switch majors because biology research requires more "hands on" activities, whereas mathematics research is all pencil and paper. She has recently been accepted into an interesting research project. She was accompanying a friend as he was discussing a quiz with his professor. Victoria asked the professor about his research, and how he planned to evaluate the proteins he had isolated. The professor asked her if she was interested in research and she explained that she has always been interested in research. Now she is the only student on a three-professor research team. Basically, the lead researcher and a visiting professor from Beijing University, has isolated *Bifido* bacteria from the colons of people living in a remote Chinese village. Colon cancer is unheard of in that village, and he thinks the bacteria or the proteins it secretes kills developing cancer cells. The focus of the research is to see if the bacteria and/or the proteins will kill lung and breast cancer cells. Victoria's job is to maintain the cancer and bacterial cells. She plans on traveling with the professor next summer to work at a university in China. Victoria is very excited to be part of this research. She stated that she would never have looked at any kind of research as a freshman if she had not been part of the Rhizobia and *Wolbachia* Projects. She felt very confident in her skills after watching other freshman in her biology class; most of them had never even used a micropipette before. Her roommate had never been in a lab before even though she went to a well-funded high school. Just recently, Victoria was one of twelve students out of 100 applicants selected for a prestigious summer research program. She will be part of a research team working with cancer cells and is extremely excited about this opportunity.

Rhizobia Project.

I was in the eighth grade when we did the Rhizobia Project. [We got to learn about bacteria]. I had never learned about bacteria in my life. [It really made me realize that research was awesome]. I had never done anything like that before. I remember [I was quite nervous] most of the time. I made quite a few mistakes in the lab, quite often. I don't know how many of the test tubes I broke. Oh, then I broke the test tube with my final results in it, and the nodules were all over the floor. It was awful! And also, a lot of the students in it were older than me and they seemed to know what they were doing, while I did not. [I remember studying the rhizobia and it has to do with the nitrogen – how it turns into a more useable form for the plants]. [We had to go to the university to work] with the rhizobia because the high school did not have any equipment at that time. The science building at the university was awesome– it was just beautiful! And the labs were huge; huge for then anyway. Because I was use to our small high school lab. [I was in awe!] [I think that this experience probably cemented that I was going to end up in some kind of science field]. Of course, I diverged to mathematics for a little bit, but I soon learned my lesson. Oh dear! Mathematics was bad.

Oh! I have recently done cell counts for the first time. The professor was talking so fast, I could not keep up with her, so I just said, "I believe you."

In the rhizobia project, we learned several skills. We started out with scales, little table scales. Oh! A balance. And the teacher was showing us how to measure things out, and it was taking us so long, I remember. The agar for rhizobia has about 10 different chemicals, so it took a long time. We learned what the autoclave was, and I kept offering to help because everything seemed really heavy, and I felt bad I could not help the teacher lift it. [We learned how to make the agar, pour plates, and transfer the bacteria]. We also toured a garden or orchard, and greenhouses.

[I enjoyed the Rhizobia Project a lot]. Also, that was my first experience with a university lab. [It made me feel more comfortable with the equipment], but I still get nervous in labs because I am so clumsy. I drop a lot of things. Especially when I haven't been in one for a while and then get back into one, and I am very timid because I am afraid I am going to mess something up that could be vital.

[I felt challenged but there was not any pressure]. [There were no tests or quizzes]. [Tests and quizzes would have added pressure and I would not have learned as much]. [We learned the skills by the teacher showing us how to do something, then we tried]. [If we needed help, she was there to help us]. She was there to fix something when we messed up, but the bacteria survived. These bacteria were resilient. However, cancer cells are not. I have learned that recently. I have killed so many cancer cells.

Significant Statements: Rhizobia Project.

- "We got to learn about bacteria".
- "It really made me realize that research was awesome".
- "I remember studying the rhizobia and it has to do with the nitrogen –how it turns into a more useable form for the plants".
- "We had to go to the university to work".
- "I was in awe".
- "I think that this experience probably cemented that I was going to end up in some kind of science field".
- "We learned how to make the agar, pour plates, and transfer the bacteria".
- "I enjoyed the rhizobia project a lot".
- "It made me feel more comfortable with the equipment".
- "I felt challenged but there was not any pressure".
- "There were no tests or quizzes".
- "Tests and quizzes would have added pressure and I would not have learned as much".
- "We learned the skills by the teacher showing us how to do something, then we tried".
- "If we needed help, she was there to help us".

Wolbachia Project.

My portion of the project was mostly just background research of the bacteria because I was in the class less often than the other students. I was dually enrolled in both biology II and chemistry. I didn't get to do a lot of lab work. We started it my junior year of high school. [It was fun, we enjoyed it a lot and learned a lot]. The information for the background came from a university's information database. [We used published research papers to get information about *Wolbachia*]. Because we had already done the Rhizobia Project, we all had some overlap of scientific knowledge for this project. But [the terminology was difficult]. The [papers were written on a high level and were moredifficult to understand]. [We had to stop every few minutes and go look up a word]. But [when they were talking about lab procedures we generally knew what they were talking about]. [Reading the research papers really helped me]. It is a whole different style of writing. In the past, I had never read a research paper of any kind. [Our teacher gave us suggestions and ways of deciphering and understanding the scientific lingo]. And, [it was intimidating at first] because there was so much we did not know. You have to do a lot to understand the papers. It is like a constant "catch up" game. You have to understand what they are saying and then translate it into something you would understand. [We did a lot of reading] and I remember asking the teacher a lot of questions. Since I was in chemistry at the same time, I missed the lab meetings where the research papers were discussed.

My part was definitely less scary to me than if I had been given one of the other positions because I could do most of my work at home. I did most of my reading at home. If I had questions, I would ask them the next day. Also, my lack of confidence in the lab! I am always afraid I am going to mess up things. I would have been terrified if I had to identify the insects. It seemed to take forever. It is hard to identify insects. Any of the other positions would have terrified me. At the same time, I think my job would have been intimidating to some of the other students.

[We had to write a paper for publication], and then we put our presentation on You Tube]. [Our paper was published in the *National Journal of High School Science]*. [We also presented our information and results to a professor that came once a year]. [I always did the introduction. I had four different spots to state information]. [Even though the *Wolbachia* Project was 2 or 21/2 years ago, I still remember all of the information]. [I think I remember the *Wolbachia* Project more than the Rhizobia Project because I was more interested in this project, I was also older, and I realized that I could really complete the *Wolbachia* Project.] [Whereas with Rhizobia Project, I really doubted myself]. [This kind of work was definitely more worthwhile, to me anyway, then a lot of my other courses]. [We did not have to take any tests, which really lessened the stress for me]. The way the school systems are now I think students, well I am still that way now, [I focus so much on not failing that I neglect to really learn the information]. [I short term memory as much as I can to pass the test]. [When that (expository) is the method of teaching you are putting a lot of pressure on the student to pass, not understand the work]. [The regular method of teaching lessens my interest in the class because I am only defined by my letter grade, not by what I learned. And that is awful.]

[I was not too nervous about presenting], I think because we did the presentation as a group. Everybody had a few slides. That helped. [It also helped that I knew what I was talking about]! That definitely helped. When I am talking about something in a history class, it is a very different story. Also, I think it helped that a lot of our other students hated speaking. [It boosted my confidence quite a bit].

Towards the end of the *Wolbachia* Project, [there was a lot of stress as we were approaching the deadline]. The students were not especially negative, but due to stress they might have said some negative things. [I remember our teacher gave us a few lectures on diplomacy]. As far as responsibility, I think it was pretty evenly given out, but different. [Everybody had different jobs]. Had I had to do the insect identification, or photography, or the lab work, I think I would have been under more stress. Well, I would have been more comfortable with lab work than the insect identification.

[I think if we would have rotated jobs, we would have learned more skills, but no one would have had the level of expertise which developed in that group]. And the project would have taken a lot longer. I don't think you would have had time to get comfortable; get in a groove.

Significant Statements: Wolbachia Project.

- "It was fun, we enjoyed it a lot and learned a lot".
- "We used published research papers to get information about *Wolbachia*
- The terminology was difficult".
- "The papers were written on a high level and were more difficult to understand".
- "We had to stop every few minutes and go look up a word".
- "When they were talking about lab procedures we generally knew what they were talking about".
- "Reading the research papers really helped me".
- "Our teacher gave us suggestions and ways of deciphering and understanding the scientific lingo".
- "It was intimidating at first".
- "We did a lot of reading".
- "We had to write a paper for publication and then we put our presentation on You Tube".
- "Our paper was published in the *National Journal of High School Science"*.
- "We also presented our information and results to the OU professor that came once a year".
- "I always did the introduction".
- "Even though the *Wolbachia* Project was 2 or 2 ½ years ago, I still remember all of the information".

- "I think I remember the *Wolbachia* Project more than the rhizobia project because I was more interested in this project, I was also older, and I realized that I could really compete the *Wolbachia* Project".
- "Whereas with the Rhizobia Project, I really doubted myself".
- "This kind of work was definitely more worthwhile, to me anyway, then a lot of my other courses".
- "We did not have to take any tests which really lessened the stress for me".
- "The way the school systems are now…I focus so much on not failing that I neglect to really learn the information. I short term memory as much as I can to pass the test".
- "When that [expository] is the method of teaching you are putting a lot of pressure on the student to pass, not to understand the work".
- "The regular method of teaching lessens my interest in the class because I am only defined by my letter grade, not by what I learned".
- "I was not too nervous about presenting. It helped that I knew what I was talking about".
- "There was a lot of stress as we were approaching the deadline".
- "I remember our teacher gave us a few lectures on diplomacy".
- "Everybody had different jobs".
- "It boosted my ego quite a bit".
- "I think if we would have had rotated jobs, we would have learned more skills, but no one would have had the level of expertise which developed in that group".

Eugenia.

Narrative Description.

Eugenia graduated from Whitesworth High School in May, 2017, and is majoring in both biology and chemistry at an honors college in a university. After completing her undergraduate coursework, she plans on going to medical school to be a pediatrician. Eugenia realizes the perseverance and commitment needed to achieve her goal. She received several scholarships which covered most of her costs for the first semester. She is proud of herself; she earned all A's and one B, which was in chemistry. Chemistry was the only class she had trouble in and felt it was due to the disorganization of the instructor. Also, when purchasing her on-line chemistry book for $ 200.00, she did not realize the purchase did not include a "hard copy" book. Next semester, besides making sure she has a different instructor, she is also going to purchase a “hard copy” book. Eugenia did not have any problems in biology. The professor posted all her notes on Blackboard; therefore, when she was in class she could concentrate on the lecture. The biology instructor did not teach straight from the book as the chemistry instructor. Eugenia felt very prepared for her biology class. It was Principles of Biology for majors. Most of the students in the class were honor students. Since it was a majors’ class, the university expected the students to come in with a certain amount of knowledge. Eugenia became part of a study group, which she found to be very helpful. A significant number of students dropped the course due to bad grades. Her biology course did not cover any topics that were not covered in high school, but the course went into more depth. She had to study but was not overwhelmed. Eugenia felt she had all the skills she needed to excel in science, all she had to do was to add more time and effort. Also, the advanced lab work she had in high school science boosted her confidence.

As for lab procedures, she was more advanced than the other students. Many of the other students had never focused a microscope before, which shocked Eugenia. The biology labs did not include electrophoresis, micropipettes or any advanced equipment. She is looking forward to next semester’s biology labs because they are supposed to be much more advanced. Chemistry labs were not difficult either, but she did have an altercation with the chemistry teacher. The teacher told Eugenia her results were too perfect, so she must be cheating. Eugenia replied with great emotion that in high school she was taught to do lab procedures over and over again until they were perfect. And that is exactly what she did. The instructor also said the Eugenia could never have had the experiences she professed in high school, but later changed her mind. It was clear that Eugenia found the altercation with the chemistry teacher extremely upsetting.

Eugenia did not have any mathematics courses this semester because she had taken college algebra at a college last summer. She does not plan to join a research team due to the rigor of her double major. She studies six hours per day, on average. Eugenia will have to take an Honor's mathematics class and a statistics class for her double major. She also took a speaking class in which she did fine. Eugenia stated that she had been active in 4H for many years and was use to giving speeches.

Eugenia did not work the first semester and does not plan to work the second semester. However, she feels she will probably have to work next year. "University is expensive!" Eugenia was shocked at the price of a meal ticket, which she was forced to buy for her freshman year. It was $ 1600.00. Next year she plans to get an apartment and cook her own meals. She did not like being in the dorm anyway because it was very noisy. Students did not observe quiet hours, and her roommate was messy.

Eugenia seems to have a realistic grasp on the rigor of carrying a double science major and then going on to medical school. She mentioned that many students say that the first semester of college is the hardest, but she knows that is not true for her. She believes that those students must be English and history majors. She is a little nervous about next semester but is fully confident she can excel.

Wolbachia Project.

[Mostly I remember reading the papers that were so hard to understand]. [We read very scientific, published, long papers that were very difficult to understand at the beginning but as you got into them they were easier to understand]. They never got easy. [This actually helped me in my college orientation class because I was reading something I had no idea what it was about, and I remembered our strategy for reading science papers about *Wolbachia*.] [So, if I could read from here to here, and understand it, I could move forward]. [The strategy I was taught to read *Wolbachia* papers really helped me in that class]. Also [I remember learning how to do all the procedures in the lab, and then having to teach them to other students]. When I had to teach the other students, it was not as hard as I thought it would be, but [I was a little bit nervous]. I knew that if I would mess up anything, then they would mess up also. [As I taught, it really boosted my ego and confidence because it went so smoothly. We all worked together to teach the new students each different part of the protocols. It made it a lot easier. [I learned leadership skills, writing skills, I also learned how to be precise and accurate. Very accurate!! Or it does not work.] My chemistry teacher this semester thought I was cheating because my numbers turned out so well. And I said no! [extreme emotion] [The way I was taught this is that you make a mistake and you go back and do it again, and again until you get it right]. And the teacher said I still do not believe you had that experience in high school, but okay. So, she kept questioning me about what we did, and I told her and then she said, oh well maybe you did get it right. And I said yes, it was complicated at first, but I know what I am doing, and I know I got this right!! I got more accurate every time and more precise every time and it was easier.

[I remember the first time we did not get results in *Wolbachia*, we were so disappointed, my confidence level dropped. But it pushed me to do better the next time. So, after we figured out what was wrong, and we solved the problem, my confidence was built back up again]. It was just one of those things where [you learn from your mistakes]. [The *Wolbachia* course did not have tests and quizzes which actually helped me learn it because not taking quizzes and tests lowers the stress and [allows you to focus on understanding the information]. You know in most classes you memorize and do it. You do not understand it. When we were doing it, you are actually understanding it and know what you are doing. So [quizzes and tests may help evaluate low level information but actually [participating in the research projects help us understand what we were doing, why we were doing it, and what the end results were.] [I really think these projects helped me love science and succeed.]

Significant Statements: Wolbachia Project.

- "Mostly I remember reading the papers that were so hard to understand".
- "We read very scientific, published long papers- very hard".
- "This actually helped me in my college orientation class because I was reading something I had no idea what it was about, and I remembered our strategy for reading science papers about *Wolbachia"*.
- "The strategy I was taught to read *Wolbachia* papers really helped me in that class [college orientation]".
- "So, if I could read from here to here and understand it, I could move on".
- "I remember learning how to do all the procedures in the lab, and then having to teach them to other students. I was a little bit nervous. As I taught it really boosted my ego and confidence".
- "I learned leadership skills, writing, and I also learned how to be precise and accurate. Very accurate! Or it does not work."

- “The way I was taught this is that you make a mistake and you go back and do it again and again until you get it right”.
- “The first time we did not get results in *Wolbachia* we were so disappointed. It pushed me to do better. We figured out what was wrong, and we solved the problem. My confidence was built back up again”.
- “You learn from your mistakes”.
- “We did not have quizzes and tests which actually helped me learn it because not taking quizzes and tests lowers the stress and allows you to focus on understanding the information”.
- “Quizzes and tests may help evaluate low level information. Participating in the research projects helped us understand what we were doing, why we were doing it, and what the end results were”.
- “I really think these projects helped me love science and succeed”.

Sarah.

Narrative Description.

Sarah graduated from Whitesworth High School in May 2017. She attended alternative school for her senior year because she was working 40 hours a week to earn money. She found alternative school very boring. Sarah had previously planned on attending a post-secondary institution to become a registered nurse but found herself in a precarious monetary situation. She got married three weeks ago and is working from 8:00 am to 5:00 pm during the weekdays at a home health establishment in a nearby town. She was working at a different establishment, but this job pays $ 1.00 more per hour. Sarah does housekeeping, home care, prepares meals and give the elderly baths. She does have a Certified Nursing Assistant License (CNA), but it is not needed for this job. Her employer does prefer that the home health workers have Cardiopulmonary Resuscitation Certification (CPR) but it is not required. Sarah also works on the weekends doing housekeeping for a few elderly residents. Her husband just recently lost his job and is looking for new employment. She hopes one day they will have enough money for both of them to go to college but does not know when or where that will be.

***Wolbachia* Project.**

I was part of the *Wolbachia* Project my junior year. My senior year I finished going to school in the alternative education program because I was working 40 hours a week to get some money. It was a struggle, but I made it through, as always. All the courses were on line and it was really boring. Just staring at a computer screen! Oh! I hated it. I preferred to be in your classroom.

The most memorable thing was when I learned what *Wolbachia* was it would take the male insects and make them female. That part really struck me as funny but also, I was concerned because if they are all female how are they going to reproduce. That is a problem and [I kept wondering is there a reverse to make the females back to males]. Other than going out into the field and collecting insects, [I did the introduction] to the little article we did. I also did some testing but not as much as other students did. I would have liked to do more of the testing, but I let the more advanced students do that. I did…Oh, it has been so long ago, that is all I can remember I did.

I think I got some of the information from website, and [we also had published professional journals to read]. I went from there and kind of did my own little conclusion of it. [I remember the early *Wolbachia* papers were in German, and I tried to translate them with my phone but that did not work out too good]. I was downloading various apps trying to take a picture of it, then I typed it into Google translate and Google did not understand it. So that didn't work.

[The project helped me because it helped me to learn better] and figure out that [there are more ways to learn then reading a book] or looking it up on line or simply asking. [It really got my interest and pushed me to learn more without asking the teacher all the time] or bugging everyone else with my questions. [It was an interesting project and I always wondered if there was a reverse to insect sex changes].

[The project was very stressful]. Other people were confused which made me confused. Once I got my brain on straight and figured out what I was supposed to do it went smoothly. [One hour of class time was not enough] to figure out what to do. That is why [it was so stressful because there wasn't enough time]. Then I would get out of that class and go to math. Ugh! [The goal of the project was to find out how many insects in our area were infected with *Wolbachia*.] We made a You Tube and published a paper. There was a lot to do, and actually it took all year. Well, no. I think we only worked on it for one semester. We also did a presentation for a professor. Being in front of the camera and a group of people bothered me because I do not like the sound of my voice. But now, it wouldn't bother me. [I really enjoyed the experience and learned a lot]. [How many people my age have published a paper, especially from little old southeast Oklahoma!]

Significant Statements: Wolbachia Project.

- "I did the introduction for our article".
- "We also had published professional journals to read".
- "I remember the early *Wolbachia* papers were in German, and I tried to translate them with my phone but that did not work out too good".
- "I kept wondering if there was a reverse process to turn the females back into males".
- "The project helped me because it helped me to learn better".
- "It really got my interest and pushed me to learn more without asking the teacher all the time".
- "It was an interesting project and I always wondered if there was a reverse to the insect sex changes".
- "The project was very stressful. One hour of class time was not enough. It was so stressful because there wasn't enough time".
- "The goal of the project was to find out how many insects in our area were infected with *Wolbachia"*.
- "I really enjoyed the experience and learned a lot".
- "How many people my age have published a paper, especially from little old southeast Oklahoma".

Nate.

Narrative Description.

Nate is a foreign exchange student from Southeast Asia and graduated from Whitesworth High School in 2016. He had already graduated from high school in his country and came to America to improve his English. Nate is currently a sophomore at a university in New Orleans and is majoring in naval architecture and marine engineering. He did not receive any scholarships because at the time he applied for university, he had the wrong type of visa to receive them. Last semester he took differential equations, chemistry II, engineering and literature. Literature was the only course in which he struggled. Nate stated the course was fiction and his brain does not do well with fiction.

He felt he was very well prepared for his courses, even though he was not an A student in his country. Nate felt that his year as a foreign exchange student at Whitesworth High School really helped him improve his English, especially reading the published science papers for the *Wolbachia* Project. “The vocabulary was so hard!” Even though English was his second language, he received a 27 on the ACT so he was not worried about being prepared for his university classes. Nate has always been good in math.

Nate would like to stay in this country, but in the present environment he does not think that is going to be possible. However, he is attending the best program in the country for naval architecture and marine engineering. Most students in his program already have employment contracts by the time they are juniors. He hopes that if he gets an engineering position the U. S. needs filled, and he will be allowed to stay in the country.

Nate mentioned again how much his English has improved. He reminisced that people had a hard time understanding him when he came to the country. His speech is so clear now that many people think he was raised in the U.S. Nate laughed about the fact that he sometimes tries to imitate the Louisiana southern accent. He did take a biology course his freshman year for non-biology majors and did fine. “I have this system where I memorize the information of courses I do not need so I can pass the test and then I just forget it”. Nate finds multiple choice tests easy because they are based on a math system and the student just has to figure out the pattern. “You don’t have to think”.

Wolbachia Project.

I remember the *Wolbachia* Project well. “My year as a foreign exchange student at Whitesworth High School really helped me improve my English, especially reading those science papers for *Wolbachia”*. American students are supposed to be poor in academics, but I was surprised by some of the students in that class, especially John. He was good! But not all of the students were, some struggled. *Wolbachia* is a bacterium that infects insects. We worked on that for one semester. [I worked with the computer and camera on insect identification and data analysis]. I did not do much lab work; I really like computers. I never used the book for identifying the insects, but Rebekah did. [It was tedious work]. We had so many insects. Oh! [I also wrote most of the abstract]. [Those science papers were so hard to read at first, but then it got easier. The vocabulary was really hard]. The students were pretty wonderful to work with. I don’t remember any problems other than the approaching deadlines. [Some students got so stressed]. But we always managed to get the work done before the deadlines. [Not having grades did not bother me, I always just try to do my best]. The presentation and YouTube were more difficult for me because [I had such a hard time pronouncing the words in front of people and the camera]. I remember those insect names were hard, and I messed some of the names up. Who think of those names anyway!? [Overall, I enjoyed working on the project].

Significant Statements: Wolbachia Project.

- “I worked with the computer and camera on insect identification and data analysis”.
- “It was tedious work”.
- “I also wrote most of the abstract”.
- “Those science papers were so hard to read at first, but then it got easier. The vocabulary was really hard”.
- “Not having grades did not bother me. I just always try to do my best”.
- “Some of the students got so stressed”
- “My year as a foreign exchange student at Whitesworth High School really helped me improve my English, especially reading those science papers for *Wolbachia”*. (Nate)
- “I had such a hard time pronouncing the words in front of people and the camera”.
- “Overall, I enjoyed working on the project”.

Horizontalizing and Clustering.

The information below (Table 1) was obtained from the first part of the interview from former students’ present situation. It was also used to write the narrative. The essence of this dissertation is to shed light on possible ways to alleviate the three factors identified by students for not entering or leaving STEM programs. The table clearly shows which students of those who participated in the projects felt prepared, cognitively and technically, for college STEM classes and it also highlights the problems students from poor rural America have funding their education.

Present Situation

a. Attending university and majoring in a STEM field
b. Prepared cognitively for science classes
c. Prepared for technology in science classes
d. Had scholarships entering university
e. Has financial issues funding university
f. Has always loved science
g. Confident in the ability to succeed

Table 1

Commonalities Among Significant Statements in Present Situation

Student	**a**	**b**	**c**	**d**	**e**	**f**	**g**
John	X	X	X	X	X	X	X
Mary	X	X	X	X	X	X	X
Victoria	X	X	X	X	X	X	X
Eugenia	X	X	X	X	X	X	X

Sarah					X		
Nate	X	X	X				X

Horizontalizing was used to identify alignment between the significant statements. Afterwards, the statements were clustered into one of five meaning units. These were technical skills, cognitive skills, professional papers (sub-topic under cognitive skills), teaching methods, and positive impressions. Then, the significant statements were also aligned under each research question to which they pertained. As per phenomenological research (Moustakas, 1994), each statement was given equal value. Rarely did statements identically overlap; therefore, few statements were eliminated. Statements clustered under the overarching research question have been identified as to whether they were textural or structural. Structural refers to how something was done in the two projects, and textural is in reference to what was done in the projects. The alignment or patterns are also addressed under research sub-question three.

Technical Skills.

- “We would go over procedures such as transferring bacteria” (John).
- “We also learned how to transfer bacteria” (Mary).
- “We learned how to prepare slides and plates” (Mary).
- “The procedures became routine” (Mary).
- “We took a safety course” (John, Mary).
- “The plants received the same amount of water” (Mary).
- “Goal of the Rhizobia Project was to see how many nodules the different rhizobia would form on the plant roots” (Mary).
- “We learned how to make the agar, pour plates, and transfer the bacteria” (Victoria).
- “We worked in the research lab down there learning how to prepare slides and plates. We also learned how to transfer bacteria” (Mary).
- “We learned how to use the micropipette and make agar” (Mary).

- “We learned procedures for caring for the plants and cultivating the bacteria” (John).
- “Each of us that participated had our own separate pot with a soybean plant in it” (John).

- “We learned how to make the agar, pour plates, and transfer the bacteria” (Victoria).
- “I remember learning how to do all the procedures in the lab” (Eugenia).
- “We had a large amount of data [in the *Wolbachia* project]” (John).
- “We would have to extract DNA from the insects found at our school’s location to try to find out which insects were infected with *Wolbachia”* (John).
- “I worked the computer and camera on insect identification and data analysis” (Nate).
- “Each of us that participated had our own separate pot with a soybean plant in it” (John).
- “We learned a lot of skills including using the micropipettes, the mini-PCR, and the electrophoresis chamber. We had to learn and how to work the centrifuge. We had to learn how to make agarose gels, how to load the dye into the DNA we had extracted and go through the process of making sure our DNA was not contaminated” (John).

Cognitive Skills.

- “We got to learn about bacteria” (Victoria).
- “I remember studying the rhizobia and it has to do with the nitrogen –how it turns into a more useable form for the plants” (Victoria).
- “We kept track of all the growth measurements in our journals” (John).
- “It was more in-depth than any of the science I had experienced” (Mary).
- “I learned leadership skills, writing, and I also learned how to be precise and accurate. Very accurate! Or it does not work” (Eugenia).
- “We measured the biomass at a later time” (John).
- “I worked with the computer and camera on insect identification and data analysis” (Nate).
- “We counted the number and size of nodules on our plants” (John).
- “I did the introduction to the little article we did. The early *Wolbachia* papers were in German, and I tried to translate them with my phone but that did not work out too well. I was downloading various apps trying to take a picture of it, then I typed it into Google translate and Google did not understand it. So that didn’t work” (Sarah).
- “We had to write a paper for publication, and then we put our presentation on You Tube” (Victoria).
- “I did the introduction for our article” (Sarah).
- “[I remember learning how to do all the procedures in the lab], and then having to teach them to other students. When I had to teach the other students, it was not as hard as I thought it was be, but I was a little bit nervous” (Eugenia).

- "I also wrote most of the abstract" (Nate).
- "I learned leadership skills, writing, and I also learned how to be precise and accurate. Very accurate! Or it does not work" (Eugenia).
- "We had to learn to keep everything organized" (John).
- "I had never learned about bacteria before in my life" (Victoria).

Professional Papers (Subtopic under Cognitive Skills).

The ability to read, analyze, and write scientific manuscripts is a cognitive skill. However, there were so many comments strictly pertaining to the use of professional scientific papers to gain information about *Wolbachia*, increase vocabulary and use strategies to understand and decode them, that I felt professional papers needed their own sub-topic.

- "I remember reading the papers that were so hard to understand" (Eugenia).
- "We used different professional published papers to obtain information" (John).
- "We used published research papers to get information about *Wolbachia"* (Victoria).
- "We had to stop every few minutes and go look up a word" (Victoria).
- "Reading the research papers really helped me" (Victoria).
- "Our teacher gave us suggestions and ways of deciphering and understanding the scientific lingo" (Victoria).
- "Those science papers were so hard to read at first, but then it got easier. The vocabulary was really hard" (Nate).
- "We did a lot of reading. It was intimidating at first" (Victoria).
- "Reading these papers was definitely a challenge" (John).
- "My year as a foreign exchange student at Whitesworth High School really helped me improve my English, especially reading those science papers for *Wolbachia"* (Nate).
- "Writing the paper for publication was definitely a challenge" (John).
- "Some of the other students really struggled with reading and understanding the papers" (John).
- "We also had published professional journals to read" (Sarah).
- "We read very scientific, published, long papers that were very difficult to understand at the beginning but as you got into them they were easier to understand" (Eugenia).
- "But the terminology was difficult. The papers were written on a high level and were more difficult to understand. But when they were talking about lab procedures we generally knew what they were talking about" (Victoria).

Teaching Methods.

- “At first, the teacher would first show us how to do it, then she would watch us as we repeated the skill. If we forgot something, she would help us through it until we were finally able to do it on our own” (Mary).
- “We would all help and encourage each other. We became a team” (Mary).
- “Slowly we began to be comfortable working with the equipment” (Mary).
- “We had to go to the university to work” (Victoria).
- “Our teacher would first explain what skills we would be learning, then she would do it herself. Afterwards, we would copy what she did. She would watch us and help us if we were doing it incorrectly. We also had our peers to help us” (Mary).
- “We learned the skills by the teacher showing us how to do something, then we tried” (Victoria).
- “If we needed help, she was there to help us” (Victoria).
- “We learned these skills through demonstrations from our teacher” (John).
- “Then we were guided through the process until we could do them ourselves. She would guide us but not give us the answers” (John).
- “Our teacher gave us suggestions and ways of deciphering and understanding the scientific lingo” (Victoria).
- “Our teacher would ask us what we were doing” (John).
- “We were grilled on content and procedure knowledge during lab meetings” (John).
- “The critical thinking our teacher put us through really helped, for example she made us solve our own problems instead of just giving us the answers” (John).
- “She made us solve our own problems. She would guide us” (John).
- “I also learned how to be precise and accurate. Very accurate!! Or it does not work” (Eugenia).
- “We had to be so particular. We were taught to try to be as perfect as possible” (Mary).
- “The way I was taught this is that you make a mistake and you go back and do it again, and again until you get it right” (Eugenia).
- “There was never anything negative, only positive encouragement” (Mary).
- “I think if we would have had rotated jobs, we would have learned more skills, but no one would have had the level of expertise which developed in that group” (Victoria).
- “It made me feel more comfortable with the equipment” (Victoria).
- “If we needed help, she was there to help us. She was there to fix something when we messed up, but the bacteria survive”. (Victoria)
- “There were no tests or quizzes. For the *Wolbachia* Project there were really no grades, everyone just got an A” (John).
- “There were no tests or quizzes” (Eugenia, Victoria).
- “The *Wolbachia* course did not have tests and quizzes which actually helped me learn it because not taking quizzes and tests lowers the stress and allows you to focus on understanding the information. You know in most classes you

memorize and do it. You do not understand it. When we were doing it, you are actually understanding it and know what you are doing. So, quizzes and tests may help evaluate low level information but actually participating in the research projects help us understand what we were doing, why we were doing it, and what the end results were" (Eugenia).

- "For the *Wolbachia* project, there were really no grades. Everyone just got an A. The point being was to eliminate studying for a grade and not studying for the knowledge. Not having to worry about a grade relieved a lot of stress. Because whenever you start worrying about grades you feel like you're not going to get something done; some students really start to stress out and their work efficiency suffers. They will not produce as good of results" (John).
- "Our peers helped us" (Mary).
- "We did not have to take any tests, which really lessened the stress for me. The way the school systems are now I think students, well I am still that way now, I focus so much on not failing that I neglect to really learn the information. I short term memory as much as I can to pass the test. When that (expository) is the method of teaching you are putting a lot of pressure on the student to pass, not understand the work. The regular method of teaching lessens my interest in the class because I am only defined by my letter grade, not by what I learned. And that is awful" (Victoria).
- "Not having to worry about a grade relieved a lot of stress" (John).

Positive Impressions.

- "I think I remember the *Wolbachia* Project more than the Rhizobia Project because I was more interested in this project, I was also older, and I realized that I could really compete the *Wolbachia* Project. Whereas with the Rhizobia Project, I really doubted myself" (Victoria).
- "I really looked forward to these trips [to the university]" (John).
- "I had never had the opportunity to work in a university lab" (John).
- "This experience helped us to realize what college would be like and made us feel more comfortable" (John).
- "Overall, I enjoyed working on the project" (Nate).
- "I really enjoyed it [the Rhizobia Project] and learned a lot" (Victoria).
- "The rhizobia experience actually helped me during my first year at college. I felt more confident and comfortable than many of the other students with using the equipment. I was quite a bit ahead of the other students" (Mary).
- "I was able to learn so much. For me, it was a turning point" (Mary).
- "This experience helped reassure me that I could be successful in marine biology" (Mary).
- "It prepared me so much" (Mary).
- "I felt challenged but there was not any pressure" (Victoria).
- "It made me feel very good about myself" (Mary).

- "The project helped me because it helped me to learn better and figure out that there are more ways to learn then reading a book or looking it up on line or simply asking questions. It really got my interest and pushed me to learn more" (Sarah).
- "I also learned how to be precise and accurate. Very accurate!! Or it does not work" (Eugenia).
- "We had to be so particular. We were taught to try to be as perfect as possible" (Mary).
- "The way I was taught this is that you make a mistake and you go back and do it again, and again until you get it right" (Eugenia).
- "It was fun, we enjoyed it a lot and learned a lot" (John).
- "It was an interesting project" (Sarah).
- "It boosted my ego quite a bit" (Victoria).
- "I was not too nervous about presenting. It also helped that I knew what I was talking about!" (Victoria).
- "I remember the first time we did not get results in *Wolbachia*, we were so disappointed, my confidence level dropped. But it pushed me to do better the next time" (Eugenia).
- "It was an interesting project and I always wondered if there was a reverse to insect sex changes" (Sarah).
- "This kind of work was definitely more worthwhile, to me anyway, then a lot of my other courses" (Victoria).
- "We all felt that it was a great accomplishment to publish a paper while we were still in high school" (John).
- "I think there would be more students majoring in the sciences if all schools had projects like this one" (Mary).
- "I remember being very anxious and really down right scared going to the university. We had never been to a university before. We became more and more relaxed in the lab" (Mary).
- "I was quite nervous [at the prospect of going to the university research lab to work]" (Victoria).
- "I really enjoyed the experience and learned a lot. How many people my age have published a paper, especially from little old southeast Oklahoma!" (Sarah).
- "Well, at first I was very anxious and really down right scared being in a university research lab. I slowly began to be comfortable working with the equipment and being in the lab" (Mary).
- "I felt very confident in my abilities after being in the *Wolbachia* Project" (Eugenia).
- "We were all pretty hesitant about working in the lab because we had never been to a university before, but we became more and more relaxed in the lab. The procedures became routine" (Mary).
- "It [the Rhizobia Project] made me feel more comfortable with the equipment" (Victoria).
- "Even though the *Wolbachia* project was 2 or 21/2 years ago, I still remember all of the information" (Victoria).

- “It [Rhizobia Project] really made me realize that research was awesome” (Victoria).
- “As I taught [other students], it really boosted my ego and confidence because it went so smoothly” (Eugenia).
- “I was in awe [going to the university to work in the research lab]” (Victoria).
- “I think that this experience probably cemented that I was going to end up in some kind of science field” (Victoria).
- “I learned more from this project than I would have learned from a regular class” (John).
- “I definitely feel the projects prepared us for college” (John).
- “We began to feel that it [publishing a paper] was definitely doable” (John).
- “We also had some organizational problems. One time our samples fell out of the freezer and got mixed up, so we had no idea of what was what anymore. We learned more from situations like that then we could have from studying a textbook” (John).
- “I really think these projects helped me to love science and succeed” (Eugenia).

Overarching Question.

What were the lived experiences of students participating in authentic research taught with cognitive apprenticeship methodology?

Textural (What was done)

- “We went to the university on weekends” (John).
- “Each of us that participated had our own separate pot with a soybean plant in it” (John).
- “We counted the number and size of nodules on our plants” (John).
- “We kept track of all the growth measurement in our journals” (John).
- “We measured the biomass of it at a later time” (John).
- “We learned procedures for caring for the plants and cultivating the bacteria” (John).
- “We learned how to make the agar, pour plates, and transfer the bacteria” (Victoria).
- “We took monthly trips to a university” (Mary).
- “Every day in school during study hall, we had to take care of our plants” (Mary).
- “Our trips to the university were on Friday, a non-school day for us” (Mary).
- “We had to take a safety course” (John, Mary).
- “I remember that the university made us take a safety course before we were allowed to work in the lab” (Mary).

- “We would go over procedures such as transferring bacteria” (John).
- “We learned how to make the agar, pour plates, and transfer the bacteria” (Victoria).
- “We worked in the research lab down there learning how to prepare slides and plates. We also learned how to transfer bacteria” (Mary).
- “We learned how to use the micropipette and make agar” (Mary).
- “We would have to extract DNA from the insects found at our school’s location to try to find out which insects were infected with *Wolbachia”* (John).
- “We learned a lot of skills including using the micropipettes, the mini-PCR, and the electrophoresis chamber. We had to learn how to work the centrifuge. We had to learn how to make agarose gels, how to load the dye into the DNA we had extracted and go through the process of making sure our DNA was not contaminated” (John).
- “I remember studying the rhizobia and it has to do with the nitrogen –how it turns into a more useable form for the plants” (Victoria).
- “We got to learn about bacteria” (Victoria).
- “I did the introduction to the little article we did. The early *Wolbachia* papers were in German, and I tried to translate them with my phone but that did not work out too well. I was downloading various apps trying to take a picture of it, then I typed it into Google translate and Google did not understand it. So that didn’t work” (Sarah).
- “We had to write a paper for publication, and then we put our presentation on You Tube” (Victoria).
- “I remember reading the papers that were so hard to understand” (Eugenia).
- “We used published research papers to get information about *Wolbachia”* (Victoria).
- “I worked with the computer and camera on insect identification and data analysis” (Nate).
- “We had to stop every few minutes and go look up a word” (Victoria).
- “Our paper was published in the *National Journal of High School Science”* (Victoria).
- “We also presented our information and results to the OU professor that come once a year” (Victoria).
- “I always did the introductions [to the power point presentation and You Tube]” (Victoria).

Structural (How it was done)

- “There were no tests or quizzes. For the *Wolbachia* Project there were really no grades, everyone just got an A” (John).
- “There were no tests or quizzes” (Eugenia, Victoria).
- “There were no tests or quizzes. For the *Wolbachia* Project there were really no grades, everyone just got an A” (John).

- "At first, the teacher would first show us how to do it, then she would watch us as we repeated the skill. If we forgot something, she would help us through it until we were finally able to do it on our own" (Mary).
- "Our teacher would first explain what skills we would be learning, then she would do it herself. Afterwards, we would copy what she did. She would watch us and help us if we were doing it incorrectly. We also had our peers to help us" (Mary).
- "We learned the skills by the teacher showing us how to do something, then we tried" (Victoria).
- "If we needed help, she was there to help us" (Victoria).
- "We learned these skills through demonstrations from our teacher" (John).
- "Then we were guided through the process until we could do them ourselves. She would guide us but not give us the answers" (John).
- "Our teacher gave us suggestions and ways of deciphering and understanding the scientific lingo" (Victoria).
- "Our teacher would ask us what we were doing" (John).
- "We were grilled on content and procedure knowledge during lab meetings" (John).
- "The critical thinking our teacher put us through really helped, for example she made us solve our own problems instead of just giving us the answers" (John).
- "We helped each other" (John).

Sub-Question 1.

What were the students' impressions, feelings, and perceptions while participating in the projects?

- "I was not intimidated by going to the university but some of the other students were" (John).
- "This experience helped us to realize what college would be like and made us feel more comfortable" (John).
- "It was tedious work" (Nate).
- "It [going to the university] was a new experience for all of us" (John).
- "It was a lot of comprehensive "hands-on" work" (Mary).
- "I also learned how to be precise and accurate. Very accurate!! Or it does not work" (Eugenia).
- "We had to be so particular. We were taught to try to be as perfect as possible" (Mary).
- "Some of the students got so stressed" (Nate).
- "The way I was taught this is that you make a mistake and you go back and do it again, and again until you get it right" (Eugenia).
- "I remember learning how to do all the procedures in the lab, and then having to teach them to other students. When I had to teach the other students, it was not as hard as I thought it was be, but I was a little bit nervous" (Eugenia).

- “I learned leadership skills, [and] writing skills” (Eugenia).
- “Overall I enjoyed the project” (Nate).
- “We had to learn to keep everything organized” (John).
- “I had never learned about bacteria before in my life” (Victoria).
- “Reading these papers was definitely a challenge” (John).
- “I had such a hard time pronouncing the words in front of people and the camera” (Nate).
- “My year as a foreign exchange student at Whitesworth High School really helped me improve my English, especially reading those science papers for *Wolbachia”* (Nate).
- “Some of the other students really struggled with reading and understanding the papers” (John).
- “We read very scientific, published, long papers that were very difficult to understand at the beginning but as you got into them they were easier to understand” (Eugenia).
- “But the terminology was difficult. The papers were written on a high level and were more difficult to understand. But when they were talking about lab procedures we generally knew what they were talking about” (Victoria).
- “There was never anything negative, only positive encouragement” (Mary).
- “If we needed help, she was there to help us. She was there to fix something when we messed up, but the bacteria survive” (Victoria).
- “I really looked forward to these trips [to the university]” (John).
- “I enjoyed the Rhizobia Project a lot. Also, that was my first experience with a university lab” (Victoria).
- “I felt challenged but there was not any pressure” (Victoria).
- “It made me feel very good about myself” (Mary).
- “The project helped me because it helped me to learn better and figure out that there are more ways to learn then reading a book or looking it up on line or simply asking questions. It really got my interest and pushed me to learn more” (Sarah).
- “It was fun, we enjoyed it a lot and learned a lot” (John).
- “Writing the paper was definitely a challenge” (John).
- “The experience prepared us for college” (John).
- “I learned more from this project than I would have ever learned from a regular class” (John).
- At the beginning of the project, most of us felt publishing a paper was completely out of reach. But as we were going through the project and actually getting results, we began to feel like this was actually doable” (John).
- “Not having to worry about a grade relieves a lot of stress” (John).
- “I never get stressed out about anything. I just keep studying” (John).
- “I was not too nervous about presenting. It also helped that I knew what I was talking about!” (Victoria).
- “I remember the first time we did not get results in *Wolbachia*, we were so disappointed, my confidence level dropped. But it pushed me to do better the next time” (Eugenia).

- “It was an interesting project and I always wondered if there was a reverse to insect sex changes” (Sarah).
- “This kind of work was definitely more worthwhile, to me anyway, then a lot of my other courses” (Victoria).
- “We all felt that it was a great accomplishment to publish a paper while we were still in high school” (John).
- “I really enjoyed the experience and learned a lot. How many people my age have published a paper, especially from little old southeast Oklahoma!” (Sarah).
- “Well, at first I was very anxious and really down right scared [being in a university research lab]. I slowly began to be comfortable working with the equipment and being in the lab” (Mary).
- “I felt very confident in my abilities after being in the *Wolbachia* Project” (Eugenia).
- “We were all pretty hesitant about working in the lab because we had never been to a university before, but we became more and more relaxed in the lab. The procedures became routine” (Mary).
- “It [the Rhizobia Project] made me feel more comfortable with the equipment” (Victoria).
- “Even though the *Wolbachia* project was 2 or 21/2 years ago, I still remember all of the information” (Victoria).
- “It [Rhizobia Project] really made me realize that research was awesome” (Victoria).
- “As I taught [other students], it really boosted my ego and confidence because it went so smoothly” (Eugenia).
- “We also had some organizational problems. One time our samples fell out of the freezer and got mixed up, so we had no idea of what was what anymore. We learned more from situations like that then we could have from studying a textbook” (John).
- “I remember I was quite nervous [being in a university research lab] most of the time” (Victoria).
- “Some of the other students felt intimidated [about working in a university research lab]” (John).
- “There was a lot of stress as we were approaching the deadline”. (Victoria)
- “One hour of class time was not enough to figure out what to do. That is why it was so stressful because there wasn’t enough time” (Sarah).
- “It was intimidating at first because there was so much we did not know” (Victoria).
- “It [Rhizobia Project] really made me realize that research was awesome” (Victoria).
- “As I taught [other students], it really boosted my ego and confidence because it went so smoothly” (Eugenia).
- “Tests and quizzes would have added pressure and I would not have learned as much” (Victoria).

- "The *Wolbachia* course did not have tests and quizzes which actually helped me learn it because not taking quizzes and tests lowers the stress and allows you to focus on understanding the information. You know in most classes you memorize and do it. You do not understand it. When we were doing it, you are actually understanding it and know what you are doing. So, quizzes and tests may help evaluate low level information but actually participating in the research projects helped us understand what we were doing, why we were doing it, and what the end results were" (Eugenia).
- "For the *Wolbachia* project, there were really no grades. Everyone just got an A. The point being was to eliminate studying for a grade and not studying for the knowledge. Not having to worry about a grade relieved a lot of stress. Because whenever you start worrying about grades you feel like you're not going to get something done; some students really start to stress out and their work efficiency suffers. They will not produce as good of results" (John).
- "Not having grades did not bother me. I just always do my best". (Nate)
- "We did not have to take any tests, which really lessened the stress for me. The way the school systems are now I think students, well I am still that way now, I focus so much on not failing that I neglect to really learn the information. I short term memory as much as I can to pass the test. When that (expository) is the method of teaching you are putting a lot of pressure on the student to pass, not understand the work. The regular method of teaching lessens my interest in the class because I am only defined by my letter grade, not by what I learned. And that is awful" (Victoria).
- "Not having to worry about a grade relieved a lot of stress". (John)
- "The project was very stressful. One hour of class time was not enough. It was so stressful because there wasn't enough time" (Sarah).

Sub-Question 2.

What commonalities or patterns were found in these experiences?

Using horizontalization to cluster the significant statements, five meaning units were identified: technical skills, cognitive skills including professional science papers, teaching methods, and positive impressions about the projects.

Technical Skills

Students remembered learning a significant number of laboratory technical skills in both projects including transferring bacteria, making agar plates, recording data about the *Glycine max* plants, using the mini-PCR, centrifuge, running electrophoresis gels, extracting DNA, and using micropipettes

Cognitive Skills

The majority of the students acknowledged improving their reading comprehension, the writing skills, leadership skills, organization skills, vocabulary, and presentation skills. The acknowledged extensively that the use of scientific professional papers to obtain information about *Wolbachia* was difficult and stressful. However, the students stated categorically reading the papers helped their literary skill tremendously. Several students commented that they still use the strategies they were taught to decipher and decode the papers.

Teaching Methods

Most students remembered some to the teaching methods used especially modeling, coaching, and scaffolding. Although they did not use that terminology, they described the processes. Some students remembered that there was no negativity or pressure, only positive encouragement. Critical thinking and being questioned about procedures and theory during lab meetings were also mentioned. There were no tests, quizzes or grades for these projects which many believed this helped relieve stress and allowed them to focus on learning.

Positive Impressions

The students remembered being taught to execute the skills they learned as perfectly as possible, and if they were not pleased with the results to re-do the skills until it was perfected. All students stated that the projects required significant laboratory and cognitive skills. They all felt they were well prepared for their university science courses because of their experiences in the projects. Several students mentioned that how failures and mistakes were used as learning tools. Most students felt that the projects helped their confidence and gave them the self-efficacy to succeed in a university STEM program. This was stated several times.

Sub-Question 3.

How do the students think these experiences have impacted their lives, especially in their choices in post-secondary education?

- "The strategy I was taught to read *Wolbachia* papers really helped me in [college course] that class" (Eugenia).
- "Reading the research papers really helped me [in college courses] (Victoria).
- "The project helped me because it helped me to learn better. It really got my interest and pushed me to learn more without asking the teacher all the time" (Sarah).
- "I really think these projects help me love science and succeed [in college]" (Eugenia).
- "Being prepared [for science courses] helped make me feel more confident in my abilities [in college]" (Eugenia).
- "I think this experience [working in the research lab] helped us to realize what college would be like and made us feel more comfortable" (John).
- "The rhizobia experience actually helped me during my first year at college. I felt more confident and comfortable than many of the other students with using the equipment" (Mary).
- "When the Rhizobia Project first started, I was really nervous. But after a few months…… I was able to learn so much. It prepared me so much. Also, I think there would be more students majoring in the sciences if all schools had projects like this one" (Mary).
- "I was in awe! I think that experience probably cemented that I was going to end up in some kind of science field" (Victoria).
- "I definitely would not have looked at any kind of research as a freshman if I had not been part of the Rhizobia and *Wolbachia* Projects" (Victoria).
- "This experience helped re-assure me that I could be successful in marine biology" (Mary).
- "After I did learn how to use all the equipment, I realized that learning to do other procedures in college would not be as difficult as I thought it would be. Especially in programs like engineering" (John).
- "The experience really prepared us for college" (John).
- "My year as a foreign exchange student at Whitesworth High School really helped me improve my English, especially reading those science papers for *Wolbachia*" (Nate).
- "This [reading published science papers] actually helped me in my college orientation class because I was reading something I had no idea what it was about I remember our strategy for reading science papers about *Wolbachia*. So, if I could read for here to here, and understand it, I could move forward" (Eugenia).

Textural and Structural Analysis

Phenomenological research requires the analysis of textural and structural data. Textural data analyzes "What was done" in the phenomenon. What happened in the phenomenon, who did it happen to, and in what order did it happen? Structural data refers to "How it was done?" For this segment of the data analysis, the meaning units or clusters for both the Rhizobia and *Wolbachia* Projects have been combined.

Textural analysis of both projects revealed the students vividly remembered learning advanced technical and cognitive skills. The Rhizobia Project focused on skills to maintain the rhizobia cultures such as making the agar, pouring the plates and transferring the bacteria to new plates without contamination. Since the high school did not have the required equipment to maintain bacterial cultures, the students traveled to a university and worked in the research lab. This was a wonderful experience for the students. It allowed to students to become comfortable with a university environment thus helping them cross cultural borders. Additional skills included care for their *Glycine max* plants plus recording growth measurements, biomass and documenting nodule size and numbers. Technical skills for the *Wolbachia* Project included extracting DNA, using the centrifuge, amplifying the DNA with PCR, making the electrophoresis gels, loading the gels, and identifying the insects. This was an intense project. Most of the students commented that their experience with advanced scientific equipment helped them realize they could be successful in a STEM field. Cognitive skills encompassed reading and analyzing published scientific papers, writing a manuscript to be submitted for publication, analyzing the data, and presenting their research.

Structurally, both projects used the same teaching methodology, cognitive apprenticeship. After a brief explanation of the subject at hand, the master teacher would demonstrate the technique, and the students would follow her lead. Coaching and scaffolding methods were used to encourage and guide the students in their methods. The first 10 minutes of lab meeting were used to question the students about procedural and content knowledge facilitating articulation and reflection. Students were expected to solve their own problems with guidance from the teacher. Problem solving facilitated exploration. Strategies for accomplishing both technical and cognitive skills were given to the students by the teacher. Peer teaching was also used promote confidence. To elevate pressure, there were no grades in either project. In addition, a positive, supportive, encouraging atmosphere was always maintained in the classroom and laboratory.

Imaginative Variation

Imaginative variation requires the researcher to look at the phenomenon from a different perspective (Moustakas, 1994). The phenomenon in question is cognitive apprenticeship methodology (Collins et al., 1989). As mentioned earlier, I decided that our "community of practice" would be a positive, encouraging, supportive community of practice. Though in the articles on cognitive apprenticeship it is not stated that the "community of practice" should be a positive one, for educators one would expect it to be a known practice. I have decided that the alternate perspective would be an environment not declared to be positive, negative or neutral. It just has not been stated or modeled.

To put an emphasis on the need for a positive environment, we are going to look at John's example for the necessity for extreme care and organization in laboratory procedures. Both Eugenia and Mary mentioned it also. The group learned quickly that lab procedures must be executed with precision and accuracy. Revisiting the situation, students were in the lab preparing to run electrophoresis gels on the DNA they had extracted from insects to check for *Wolbachia* infection. Extracting DNA to check for *Wolbachia* is a lengthy process, 24 steps. There was a "buzz" of chatter as they set up the electrophoresis chambers and prepared the gels. One student quickly removed the microfuge tube rack from the freezer and the rack dropped to the floor. There were about 30 samples of DNA in the rack. The samples were identified by the racks grid, for example C2 and C2 would have been identified in their lab books as *Apis mellifera*, honeybee. Now, the DNA samples were not identified and rendered worthless. The moment the rack hit the floor, there was dead silence. Everyone knew the consequences of that event. The most predictable reaction from the students would have been negative comments, criticism, and assigning blame for the action. Though work would have continued toward the common goal of producing the 3 artifacts by the end of the semester, I do not believe work would have been as efficient or facilitated the individual cognitive grow that the positive, supportive environment did.

Another example for the need to create a positive environment, is the uneven work load of the students. The students had voted at the beginning of the project not to rotate responsibilities. I actually did not agree with this, but they were in charge. All of the students had different capabilities and levels of expertise, which is normal for a class. Some of the workloads were much more time consuming than others. Personally, I thought this would become a contentious issue as the end of the semester approached. Likewise, I expected the uneven workloads to be mentioned in the interviews. This never happened. The students were satisfied that everyone was just “trying their best”. Nothing more was said. I believe the lack of hostility and negativity was due to the master teacher modeling and encouraging a positive atmosphere in our “community of practice”.

Synthesis

Introduction.

All of the students interviewed for this study, have positive memories of the projects. They stated that the projects were an overwhelming influence in their choice of majors, STEM self-efficacy, preparation for college, and mastery of skills. Two of the students, Sarah and Nate enjoyed the *Wolbachia* project, however the project did not have the impact on their lives as it did the four other students. Nate was a foreign exchange student and intended to pursue a STEM major regardless of his experiences in an American high school. Sarah, who at one time intended to become a registered nurse, found herself in a precarious financial situation and was unable to focus on a professional career. For the other four students interviewed, the projects seemed to can compile a pathway or scenario for encouraging, developing and retaining STEM majors from underrepresented populations. All of these students, with the exception of the foreign exchange student are low income, remote rural students. Four are female, one Choctaw Native American, and one is male.

Three of the students, John, Victoria, and Mary participated in the Rhizobia Project. Eugenia, Nate and Sarah were not attending Whitesworth High School at the time. Work for the project took place on the weekends and during study hall therefore the students had to have the initiative to take part in the project without pressure of grades and participate on their own free time. There were no academic requirements to be part of this project, just an interest in science. Personally, I feel this is imperative. The students had to be willing to pursue science without academic pressure. At that time, two of the students were in the eighth grade and one in the ninth. They were young, and their exposure to science, the equipment, and to universities continued throughout their high school years. During the interview, students were not asked about university outreach programs other than the Rhizobia Project, but most of them mentioned the “Research Experience for High School Students" (REHSS) on their own and stated how important it was to them. A few students also mentioned another outreach program associated with the *Wolbachia* project. The biotechnology department at a central college supplied most of the equipment and chemicals for the project.

The Rhizobia Project.

The students’ initial exposure to open-inquiry research, the Rhizobia Project, was positive and without pressure. It was the first time they had been to a university research lab. “We had to go to the university to work” (Victoria). “I really looked forward to these trips. But some of the other students felt intimidated” (John). “Also, that was my first experience with a university lab. I was in awe!” (Victoria). Both John and Mary remembered taking a safety course before the university would allow them to work in the lab, but Victoria did not mention it. Victoria and Mary felt timid about working in the lab. “It was intimidating at first because there was so much we did not know. I remember being quite nervous most of the time” (Victoria). “We were all pretty hesitant about working in the lab. I remember being very anxious and really down right scared going to the university. Slowly we began to be comfortable working with the equipment and being in the lab” (Mary).

“The goal of the Rhizobia Project was to see how many nodules the different rhizobia would form on the plant roots” (Mary). “We got to learn about bacteria! I remember studying the rhizobia and it has to do with the nitrogen how it turns into a more useable form for the plants” (Victoria). All three students remembered technical skills taught during the project. “We would go over procedures such as transferring bacteria” (John). “We learned how to make the agar, pour plates, and transfer the bacteria” (Victoria). “We learned procedures for caring for the plants and cultivating the bacteria” (John). “Each of us that participated had our own separate pot with a soybean plant in it. We had to measure the biomass at a later time. We counted the number and size of nodules on our plants and recorded them in our journals” (John). “The plants received the same amount of water” (Mary). As to the teaching methods, the students’ memories were very similar as well. “We had to be so particular. We were taught to try to be as perfect as possible” (Mary).

> At first, the teacher would first show us how to do it, then she would watch us as we repeated the skill. If we forgot something, she would help us through it until we were finally able to do it on our own. We would all help and encourage each other. We became a team (Mary).

“We learned these skills through demonstrations from our teacher” (John). “There was never anything negative, only positive encouragement” (Mary). All three of the students felt the experience had a positive impact on their lives. “It was more in-depth than any of the science I had experienced. It made me feel good about myself" (Mary). "This experience helped us to realize what college would be like and made us feel more comfortable" (John). "I really enjoyed it [the Rhizobia Project] and learned a lot" (Victoria). "The rhizobia experience actually helped me during my first year at college. I felt more confident and comfortable than many of the other students with using the equipment. I was quite a bit ahead of the other students. It prepared me so much" (Mary). "I felt challenged but there was not any pressure" (Victoria). "For me, it was a turning point. This experience helped reassure me that I could be successful in marine biology" (Mary). "This experience made me realize that research was awesome!" (Victoria). "I think there would be more students majoring in the sciences if all schools had projects like this one" (Mary).

The *Wolbachia* Project.

All students interviewed, with the exception of Mary, participated in the *Wolbachia* Project. This project required self-discipline, and mastery of complex skills, both cognitive and technical.

> We learned a lot of skills including using the micropipettes, the mini-PCR, and electrophoresis chamber. We had to learn how to work the centrifuge. We had to learn how to make agarose gels, how to load the dye into the DNA we had extracted and go through the process of making sure our DNA was not contaminated (John).

For this project, the students decided not to rotate responsibilities. "Everybody had different jobs. I always did the introduction" (Victoria). Their rational was that each student would then become proficient in one area allowing for the development of expertise. "I think if we would have had rotated jobs, we would have learned more skills, but no one would have had the level of expertise which developed in that group"

(Victoria). John, Eugenia and another student did most of the intensive lab work. All students were involved with loading and running the gels. Nate was in charge of insect identification, computer analysis and camera interface. “I worked with the computer and camera on insect identification and data analysis” (Nate). There was also another student helping him with these responsibilities. Victoria and Sarah wanted to be mostly involved with writing the paper, so they had few lab responsibilities.

> I did the introduction to the little article we did. The early *Wolbachia* papers were in German, and I tried to translate them with my phone but that did not work out too well. I was downloading various apps trying to take a picture of it, then I typed it into Google translate and Google did not understand it. So that didn’t work (Sarah).

All students were required to read and analyze the professional science papers plus help write the paper. This was true well as for the You Tube and presentation. “We also presented our information and results to the OU professor that came once a year” (Victoria). Cognitive apprenticeship methods along with positive encouragement were used throughout the project. “We learned skills by the teacher showing us how to do something, then we tried” (Victoria). “Then we were guided through the process until we could do them ourselves. She would guide us but not give us the answers” (John). Strategies for solving problems were always given to the students to help them solve their own problems. “Our teacher gave us suggestions and ways of deciphering and understanding the scientific lingo” (Victoria). “The critical thinking our teacher put us through really helped, for example she made us solve our own problems instead of just giving us the answers” (John). “If we needed help, she was there to help us” (Victoria).

Comments on reading and analyzing the professional papers were present in all of the *Wolbachia* interviews and commented on earlier. Despite the stress and difficulty of working with the papers, impressive cognitive growth results from this experience. "We read very scientific, published, long papers that were very difficult to understand at the beginning but as you got into them they were easier to understand" (Eugenia). "Some of the students really struggled with reading and understanding the papers" (John). "Reading the research papers really helped me" (Victoria). "They [the research papers] really helped me improve my English. The vocabulary was so hard" (Nate).

However, throughout all of the arduous work the students were proud of themselves for publishing a paper while they were still in high school and enjoyed the process. "Overall, I enjoyed working on the project" (Nate). "It really got my interest and pushed me to learn more" (Sarah). "It was fun, we enjoyed it a lot and learned a lot" (John). "It boosted my ego quite a bit" (Victoria). "I felt very confident in my abilities after being in the *Wolbachia* Project" (Eugenia).

In conclusion, the projects provided a stimulating environment or lived experience with indications of positive mental and emotional growth was possible for all of the students. Initial responses to the projects, whether going to a university research lab to work or publishing a scientific research paper while still in high school, was met with doubt. The students struggled with gaining the skills necessary to reading, analyze and write science manuscripts. Slowly as the students mastered the skills and confidence seemed to rise. Protocols, initially executed haphazardly, were followed with expert precision which was documented by the results. Collaborative team work appeared to increase. Self-efficacy seemed to be apparent. Towards the end of the *Wolbachia* Project, publishing a science paper while still in high school seemed obtainable to the students. Tremendous grow in literacy was documented by the fact that the students final paper was accepted for publication. By the end of the Rhizobia Project, the students seemed to feel perfectly at home in the lab and with their ability to execute the protocol perfectly. Unanimously, the students felt they learned as much or maybe more from their errors as they did their successes. Personally over time, I watched them change from a group of disorganized unconfident teenagers into a responsible team of apprentice scientists.

Chapter 5: Discussion, Conclusions, and Recommendations

For the last several decades, the United States has been in a quagmire situation regarding qualified STEM applicants. The recruitment of individuals into STEM post-secondary institutions is low, and the attrition rate from these programs is high (National Science Board, 2010, 2012, 2015; President's Council of Advisors on Science and Technology, 2012). In order to resolve this problem, post-secondary institutions must increase recruitment, and decrease attrition in underrepresented populations such as minorities and women (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2011; National Science Board, 2010, 2015; President's Council of Advisors on Science and Technology, 2012). However, even if individuals from the underrepresented population declare STEM majors, they are prone to drop out of the program (Korn, 2015; National Center for Education Statistics, 2014).

Three factors have been identified for this underlying problem. These factors are (a) lack of authentic scientific research experiences (American Association for the Advancement of Sciences, 2017; Committee on Science and Technology, 2007; National Science Board, 2015; National Science Teachers Association, 1998; Oriz & Sriraman, 2015); (b) lack of high school academic preparation, especially in mathematics (Dika & D'Amico, 2016; Goldman, et al., 1976; Hackett & Betz, 1981; Sells, 1973); and (c) differences between the culture of science and the social culture of the students (Aikenhead, 1996, 1998; Costa, 1995). Numerous science agencies and institutions have advocated the use of open-inquiry research methods to help resolve this problem (American Association for the Advancement of Sciences, 2017; Committee on Science and Technology, 2007; National Science Board, 2015; National

Science Teachers Association, 1998)**.** Open-inquiry research requires students be given a framework of possible research topics. From the framework, students construct their own research questions and methods. The students then collect the data, analyze it, and come to a conclusion (National Science Teachers Association, 1998). The American Association for the Advancement of Sciences (2017) specifically endorses conceptual framework methodologies that incorporate authentic science research in classrooms. One conceptual framework for implementing open-inquiry research in the classroom is cognitive apprenticeship. Cognitive apprenticeship creates a “community of practice” where master and apprentice work together in research. The methodology uses modeling, coaching, scaffolding, articulation, exploration and reflection to promote construction of knowledge (Collins, et. al., 1989). In addition to these methods, students only received positive feedback and encouragement from me and each other, plus there were no grades. I was determined to make our “community of practice” a positive, supporting and encouraging community. Negative comments were not tolerated. There were no grades because I wanted the students to be motivated by their quest for knowledge, not desire for a grade. Open-inquiry research advocate’s student determination of the research questions and construction of knowledge to promote ownership in the research (American Association for the Advancement of Sciences, 2017).

This phenomenological study used cognitive apprenticeship methods to teach two, open-inquiry projects, the Rhizobia and the *Wolbachia* Projects. Due to the relationship between the research questions, there is overlap of information in the answers. The overarching question of this study was: what were the lived experiences of students participating in authentic scientific research that was guided by cognitive apprenticeship methodology? In addition, the following sub-questions further guided the research on this topic:

1. What were the impressions, feelings, and perceptions of these students while participating in the projects?
2. What commonalities or patterns were found in these experiences?
3. How did the students' experiences influence their lives, especially in their choices to pursue post-secondary education?

Overarching Question.

The experiences of the students participating in the projects were divided into textural and structural patterns. As mentioned earlier, textural relates to “what” was done, and structural refers to “how” it was done. Despite the fact that the projects took place several years ago, the students had vivid memories of their experiences. Two students participated in both projects, one student was only in the Rhizobia Project, and three students were solely in the *Wolbachia* Project. To participate in the Rhizobia Project, the students volunteered to go to the university on weekends to learn microbiology skills, plus took their study hall time during the week to care for their *Glycine max* plants and record data. John and Mary both mentioned this, though Victoria did not. Personally, I feel this is very important; it showed a fundament interest and desire to engage in scientific research.

All of the students clearly remembered the technical skills they learned from maintaining the bacterial cultures, making the agar, extracting the DNA, running the PCR, running electrophoresis gels and many more. This was a major theme in the interviews and was identified as one of the meaning units. As for cognitive skills, learning to write in a scientific format by reading professional papers was a major topic of discussion, and was identified as another meaning unit in the interviews as a sub-topic. The students acknowledged the difficulty of the tasks, but also commented how this helped increase their vocabulary, their writing skills, plus their decoding or deciphering strategies. Mastering biological research techniques helped build confidence in all of the participants, and this will be addressed under research questions two and four. Several students mentioned how both the technical and cognitive skills helped them in their university classes. Students majoring in biology spoke of being more advanced than their university peers. Surprisingly, some of the students in their university biology classes had never focused a microscope or used a micropipette. Students briefly spoke of leadership skills, writing the article to be submitted for publication, making the You Tube, peer teaching, and organizational skills. Problem solving was cited as well. Students were encouraged to solve their own problems with guidance from their teacher. When the *Wolbachia* Project began, several times students would rush through the 24-step process of extracting the DNA, only to have no results.

> I remember the first time we did not get results in *Wolbachia*, we were so disappointed, my confidence level dropped. But it pushed me to do better the next time. So, after we figured out what was wrong, and we solved the problem, my confidence was built back up again. It was just one of those things where you learn from your mistakes. I also learned how to be precise and accurate. Very accurate! Or it does not work (Eugenia).

The last incident where lack of precision and accuracy caused a problem was explained by John. I personally think this was a turning point in the project. The students stopped behaving like enthusiastic teenagers and started behaving like apprentice scientists. About thirty frozen DNA samples where in a microfuge tube rack.

The students were getting ready to run some electrophoresis gels to check for *Wolbachia* infection. The rack had a letter, number grid so the samples were identified, for example as C2. The insect identification for C2 was in their lab books. Students were busy talking and setting up the equipment. One student quickly pulled the rack from the freezer, and the samples fell out of the rack on to the floor. Instantly there was dead silence in the lab. Everyone realized the significance of this event. Their 30 DNA samples were now not identified, and all of the work was for naught. After this incident, I never observed one student not adhering to strict protocols in the lab. They began to look like a professional research team.

> We also had some organizational problems. One time, our samples fell out of the freezer and got mixed up, so we had no idea of what was what anymore. We learned more from situations like that then we could have from studying a textbook (John).

These are two examples of how the students realized they were fully responsible for their actions. To their credit, I never heard any negative comments toward a team member who made a mistake. The student who dropped the microfuge tube rack was not reprimanded by anyone. There was only positive encouragement and guidance. In retrospect, I now realize they were copying my philosophy of creating a positive, supportive “community of practice”.

The structural elements in both projects were cognitive apprenticeship methods. (Collins et al., 1989). The students remembered being taught by demonstration, or modeling, and they would try to copy the skill. Positive encouragement, guiding and supportive help by the teacher was also mentioned. Several students referred to helpful comments from their peers, and the benefits of peer teaching. On student, Eugenia, stated that peer teaching really boosted her confidence and ego.

> Also, I remember learning how to do all the procedures in the lab, and then having to teach them to other students. When I had to teach the other students, it was not as hard as I thought it would be, but I was a little bit nervous. I knew that if I would mess up anything, then they would mess up also. As I taught, it really boosted my ego and confidence because it went so smoothly (Eugenia).

Students fondly remembered the yearly visits by a university professor, although the visits were not part of the projects. Since the same teaching methods were used, the students recognized the connection between the professor's program and the projects. During these visits, the students would present their research to him, which allowed for articulation and reflection. The professor was known for asking detailed, comprehensive questions. A few of the quotes (Table 2) have been aligned with cognitive apprentice methods used that the students remembered, positive feedback, and the professor's outreach program.

Table 2

Alignment Between Students' Quotes and Methods Used in the Projects

Cognitive Apprenticeship Method	**Student Quote**
Modeling	"At first, the teacher would show us how to do it, then she would watch us as we repeated the skill" (Mary).
Coaching	"If we forgot something, she would help us through it until we were finally able to do it on our own" (Mary).
Scaffolding	"She would guide us but not give us the answers" (John).
Articulation	"I was not too nervous about presenting. It also helped that I knew what I was talking about" (Victoria). "We were grilled on content and procedure knowledge during lab meeting" (John).
Reflection	Not mentioned by the students
Exploration	"She made us solve our own problems" (John).
Positive Guidance & Encouragement	"There was never anything negative, only positive encouragement" (Mary).
University Outreach Program	"Another thing that helped me, was the visits by the professor. He would bring equipment and work with us all day. I had never had that kind of contact with a college professor. It made me feel more comfortable about going to college" (Mary).

Grades were another major topic of conversation during the interview, and a significant structural element in the study. During the interview I merely asked, "What about grades?" I was not prepared for emphasis and weight of the students' comments. Neither project had grades. The Rhizobia Project was not connected to a class, and in the *Wolbachia* Project all students received an A regardless of the workload or responsibility. I thought differing workloads might be an area of contention among the students, but it was not. Almost every student stated that there were no quizzes, tests, or grades. Several students mentioned how this relieved stress and allowed them to concentrate on the task or information at hand.

> The *Wolbachia* course did not have tests and quizzes which actually helped me learn it because not taking quizzes and tests lowers the stress and allows you to focus on understanding the information. Quizzes and tests may help evaluate low-level information but actually participating in the research projects helped us understand what we were doing, why we were doing it, and what the end results were (Eugenia).

> Not having to worry about a grade relieved a lot of stress. Because whenever you start worrying about grades you feel like you're not going to get something done; some students really start to stress out and their work efficiency suffers. They will not produce as good of results (John).

> The regular method of teaching (expository) lessens my interest in the class because I am only defined by my letter grade, not by what I learned. And that is awful (Victoria).

These are powerful statements and deserve some reflection by the professional education community. Student evaluations are important, but perhaps there are other ways of evaluating students that would facilitate relieving stress.

Sub-Question 1

This question examined the impressions, feelings, and perceptions of the students as they were participating in the projects. The interviews pointed to almost universal responses about the projects. Unanimously, the students enjoyed both projects, felt that they learned more from the projects than regular classes, and believed these projects helped increase their confidence to succeed in STEM related fields. The increased confidence was mainly due to mastering the cognitive and technical procedures plus publishing a scientific paper at such a young age. My favorite quote from all of the interviews came from Sarah. “I really enjoyed the experience and learned a lot. How many people my age have published a paper, especially from little old southeast Oklahoma!” (Sarah).

For students taking part in the Rhizobia Project, initially there was a general feeling of intimidation and nervousness about working in a university research lab. This feeling gradually changed to state of comfort and confidence as the students fell into a routine work pattern. “Well at first I was very anxious and really downright scared being in a university research lab. I slowly began to be comfortable working with the equipment and being in the lab” (Mary). “It [the Rhizobia Project] made me feel more comfortable with the equipment” (Victoria). All three students who were part of the Rhizobia Project stated the positive impact this had on their confidence to be successful in a STEM major at university, which will be addressed in question four. The Rhizobia Project was my first attempt at implementing open-inquiry research in a school. It was not as rigorous as the *Wolbachia* Project. The students helped analyze some of the data they recorded, but the paper was written by the professor that allowed us to use the research lab. Therefore, it did not provide for the rich learning environment found in the *Wolbachia* Project.

The *Wolbachia* Project created a stimulating scientific research climate for both the students and myself. It provided a comprehensive, intense exposure to complex technical and cognitive skills. The students have stated emphatically how much they learned and that the project helped them develop the skills and confidence needed to be successful in university classes. Sarah, the only student interviewed not attending university explained that the project showed her there are different ways to learn. “The project helped me because it helped me to learn better and figure out that there are more ways to learn then reading a [text] book". Overwhelmingly, they expressed a great sense of accomplishment, confidence, interest, and an increase in problems solving and organization skills over and above the technical and language skills they learned. The only negative feelings associated with the *Wolbachia* Project were stress and the difficulty of dealing with the professional papers. "There was a lot of stress as we were approaching the deadline" (Victoria). Though all students did acknowledge the papers were excellent learning tools. Of course, the stress changed to happiness and excitement as they met their deadlines and published their paper. From my prospective, the two males interviewed, John and Nate, did not share the stress of the females. Whether this is related to gender, individual personalities or culture, I do not know. John and Nate both realized other team members felt stress though they did not.

Participation in the projects resulted in many benefits for the students. From a teacher's perspective I saw a significant increase in diplomacy, self-discipline, self-respect, collaborative skills, and sense of responsibility in the students. In hindsight, I would probably agree with Sarah. "One hour of class time was not enough to figure out what to do. That is why it was so stressful because there wasn't enough time". To put this statement in perspective, there is an unwritten rule at this small rural school high school that students are not expected to do anything academic after they leave the school. The students slowly came to the realization they were responsible to complete their portion of the research regardless of class time. They would have to come in before school, during free time, and afterschool to complete their research. PCR alone takes two hours. This is why student ownership of the project is so important. The students must embrace the research, formulate the research questions, and agree on the end products. The students must be in charge of the project; the teacher is only there for guidance and to be a team member.

Sub-Question 2

This question addressed commonality of patterns found in the interviews by clustering statements into meaning units. Five meaning units or patterns were identified; technical skills, cognitive skills, professional papers (a subtopic of cognitive skills), teaching methods, and positive impressions. Technical skills, the importance of learning them and mastering the equipment, were mentioned by all students except Sarah. The three students majoring in biology unanimously stated that mastering the equipment and skills gave them confidence in their STEM abilities and prepared them for university classes. The equipment these students used were entirely supplied by grants and outreach programs.

Cognitive skills, in conjunction with professional papers, were prominent in the interviews. It is impossible to communicate the increase in literary skills I saw in the students due to their exposure to these papers. They had never seen a professional paper before, and to my surprise, they knew nothing about citing references. Even the seniors were devoid of this knowledge. The increase in all literary skills was dramatic. Following cognitive apprenticeship methods, the students had been given strategies for dealing with these papers. A lot of time was spent, one on one, with the students decoding the papers. Several strategies were used. Areas of information for the background were divided up among the students, therefore, they all were responsible to read and summarize different information. They were taught to circle every word they did not know and look up the meaning. “We had to stop every few minutes and go look up a word” (Victoria). Then after reading 2 or 3 paragraphs, they were required to explain the information to me. This strategy was very helpful. “Our teacher gave us suggestions and ways of deciphering and understanding the scientific lingo” (Victoria). We usually had two, ten-minute lab meetings a week. I would ask them a few questions, but mostly one student was assigned the task of explaining a paper to the group, which allowed for articulation. After presenting the information, others in the group would ask questions. This helped the speaker clarify their comments, and it also highlighted areas were the speaker’s comprehension of the material was not adequate. By using the professional papers, students became aware of how limited and elementary their present literary skills were, and they tried to emulate the language and syntax in the papers. The strategies were exceptionally successful.

The teaching methods used were identified as another meaning unit. All students stated the methods facilitated learning, confidence, and a positive atmosphere.

The students did not make any references to reflection; however, it was used in conjunction with modeling, coaching, scaffolding, articulation and exploration. Quotes referencing the different teaching methods (See Table 2) have been aligned earlier in a chart. “The teaching procedures used in this project [*Wolbachia*] were much better than the ones used in other classes. This was a hands-on project” (John). Personally, I feel the positive atmosphere, modeled by me and copied by the students, also helped to make this program so successful. Many of the students from this remote, rural school have low self-esteem and confidence. If negative comments and blame had been allowed, I do not think the students' confidence levels would have increased so dramatically.

Sub-Question 3

This research question focused on the impact students felt these projects had on their lives and choices in post-secondary education. Of course, Sarah is the only student not attending a university. But the project did impact her life. "This project helped me learn better. It really got my interest and pushed me to learn more without asking the teacher all the time" (Sarah). Plus, she was very proud to be a published author in high school. For the other students, the evidence is formidable.

The projects had a strong influence on Victoria. "It [Rhizobia Project] really made me realize that research was awesome" (Victoria). She is now majoring in biology, minoring in chemistry and involved in two research projects. The first one with a professor researching *Bifido* bacteria and its inhibition of cancer cell growth, and she has just recently been chosen as a research scholar and will be working in cancer research all summer. "I would have never considered being part of a research team as a freshman if I had not been in the Rhizobia and *Wolbachia* Projects" (Victoria).

John has always loved science and is majoring in computer engineering. He feels both projects helped him become comfortable about attending college and helped him develop skills to be successful in a STEM field. "I think this experience [working in the research lab] helped us to realize what college would be like and made us feel more comfortable" (John). "After I did learn how to use all the equipment, I realized that learning to do other procedures in college would not be as difficult as I thought it would be. Especially in programs like engineering" (John).

Mary, who is majoring in biology and finishing her sophomore year in college, also stated the benefits of the Rhizobia Project. "The rhizobia experience actually helped me during my first year at college. I felt more confident and comfortable than many of the other students with using the equipment" (Mary). "This experience helped re-assure me that I could be successful in marine biology" (Mary). "I learned so much" (Mary).

Eugenia expressed gratitude for the *Wolbachia* Project as well. She is presently majoring in both biology and chemistry. Afterwards she intends on going to medical school. "The strategy I was taught to read *Wolbachia* papers really helped me in [the college orientation course] that class" (Eugenia). "Being prepared [for science courses] helped make me feel more confident in my abilities [in college]" (Eugenia). "I really think these projects help me love science and succeed [in college]" (Eugenia).

Nate, the foreign exchange student, is majoring in naval architecture and marine engineering and has always intended to enter a STEM field. He felt the *Wolbachia* Project mainly helped him with his English. "My year as a foreign exchange student at Whitesworth High School really helped me improve my English, especially reading those science papers for *Wolbachia*. The vocabulary was so hard! (Nate).

These two projects addressed the three factors identified as the underlying problem underrepresented populations, mainly women and minorities, have a low recruitment rate and a high attrition rate in post-secondary STEM majors. The factors are (a) lack of authentic scientific research experiences (American Association for the Advancement of Sciences, 2017; Committee on Science and Technology, 2007; National Science Board, 2015; National Science Teachers Association, 1998; Oriz &

Sriraman, 2015; Trent & Baber, 2015); (b) lack of high school academic preparation, especially in mathematics (Dika & D'Amico, 2016; Goldman, et al., 1976; Hackett & Betz, 1981; Sells, 1973; Trent & Baber, 2015); and (c) differences between the culture of science and the social culture of the students (Aikenhead, 1996, 1998; Costa, 1995; Hill, 2015; Trent & Baber, 2015). Both projects included authentic research. The Rhizobia Project researched the nodulation rate of two drought resistant strains of rhizobia. These strains were isolated during the Oklahoma drought of 2011, and were thought to be a viable method of fixing nitrogen for crops in case of further droughts. The *Wolbachia* Project is also an example of authentic research. *Wolbachia* infestation of insects is reducing the number of insects in ecosystems. Insects are an important part of food webs, and a decrease in their numbers impacts the amount of energy available in trophic levels. There is a national *Wolbachia* study to evaluate the endosymbionts effects on insect propagation. The professional science papers addressed the lack of academic preparation mainly in literacy. The papers were "peer reviewed" published science research papers. The vocabulary, sentence structure, and organization of the papers were superior. I mentioned this before but seeing the writing level of professional papers helped the students realize their limited literacy skills. The strategy given the students to decode the papers helped them to understand and analyze the data being communicated. Students then aspired to emulate the writing level and vocabulary of the papers. The projects created a "scientific community of practice" which helped the students cross the cultural borders from their social culture to that of science. To engage in these authentic research projects students had to become apprentice scientists by mastering the technical and cognitive skills required for the research. This helped them to create a “science identity”.

Theoretical framework is imperative if a study is to be valid. Grant and Osanloo (2014) describe it as the foundation of a study and compare theoretical framework to the blueprint of a house. “It is derived from an existing theory in literature” (Grant & Osanloo, 2014). The theoretical framework of this study was acquired from the literary works of John Dewey and Lev Vygotsky. John Dewey (1938/ 1997) took a pragmatic view towards education. He believed a child’s education should be based on experiences that aligned with the student’s interests while also increasing in difficulty. One experience should build on another. Education must be active and social (Dewey, 1938/ 1997). Both projects adhered to this theory. Students were interested in the projects or they would not have volunteered to participate in them. Participation in the projects was not mandatory. Skills, both technical and cognitive, were taught starting with basic procedures and strategies before addressing the more complex ones. The projects included abundant socialization and activity. Lev Vygotsky (1978) ZPD advocates more advanced individuals, both students and teachers, work socially with the less advanced students to communicate skills, culture and behavior. During the projects, the culture of science was communicated and practiced by all participants. Peer teaching was also utilized, which was normally quite successful for both students. Eugenia mentioned how her ego was boosted by teaching the new students. The success of the projects was due to solid theoretical and conceptual frameworks, the creation of a positive, encouraging “community of practice” plus the outreach programs that made them possible. To me, the implications of this study are clear. Solving the deficit of qualified STEM candidates in the United States is certainly solvable.

Limitations

Personally, I feel there were two limitations in this study. The first pertains to the length of time between the projects and the interviews. The Rhizobia Project was five years ago and the *Wolbachia* Project was two years ago. Humans have the tendency to forget negative aspects of an experience and remember the positive. Therefore, their memories of the experiences may not be exactly accurate. The second limitation was the students' general allegiance and affection for me. This may have also clouded their recollections of the two projects. However, their statements and memories align quite closely with my own. If I were designing these projects for the future, I would have allowed a little more time for the *Wolbachia* Project, maybe a month or two. But otherwise, I would not have changed a thing. Truly, the results were amazing. As for the Rhizobia Project, I would have required the students to take a more active part in writing the manuscript for publication.

Implications and Future Research

To me, the implications of this study are speak for themselves. Solving the deficit of qualified STEM candidates in the United States is certainly solvable. Trent and Baber (2015) studied the low numbers of women and minorities in STEM fields focusing specifically the factors causing it, and solutions to solving the problem. They tracked university enrollment, analyzed the interventions used, and documented students' experiences (Trent & Baber, 2015). They found the factors contributing to this situation were, lack of academic preparation, lack of science identity and lack of exposure to authentic research. Solutions included exposure to rigorous academic classes, experiences in authentic research in middle and high school which allows students not only to develop the skills they need but also to develop a "science identity" (Trent & Baber, 2015). Harvey Mudd College increased women's enrollment in computer science from 12% to 40% in five years by providing students with early research opportunities, revising computer courses to include applications and send women to the Grace Hopper Celebration of Women in Computing (Hill, 2015). These are examples of what can be done. However, it needs a synergistic effort by all educational institutions, state and federal government agencies, plus parents, teachers and students. It is necessary to revisit the meaning units from this study; technical and cognitive skills, teaching methods, and positive impressions. What made these projects so successful? From my perception, first and foremost were the teaching methods. These methods included cognitive apprenticeship methodology, no grades, and positive environment which encouraged students to take ownership of the research. There were no negative repercussions in the projects. I truly believe that if most elementary and middle school programs were taught with these methods, more students would be encouraged to take advanced high school science classes and to enter post-secondary STEM programs. Science is a great vehicle for teaching literacy. Teachers in elementary and middle school may need professional support concerning ideas and knowledge for research projects, but expensive equipment is not required. The Association for the Advancement of Sciences (2017) offers support and help on its website. High school research projects do need expensive equipment. Most public schools cannot afford the equipment, especially poor rural and intercity schools. Grants and outreach programs have to come forward to fill the void. I know the National Science Foundation advocates outreach programs between high school and universities in its grant program. Next is student mastery of technical and cognitive skills. This is important for student confidence and preparation for college STEM programs. They must have access to the equipment in order to master the skills. Many professional papers on published on-line now, so obtaining them is not problematic. The last meaning unit was positive impressions. Aside from their anguish and stress in mastering the professional papers, all of the students enjoyed the projects and enjoyed learning. Personally, I think that is what all students' education should reflect – a positive, encouraging stimulating environment that nourishes young minds to grow.

Conclusion

For our country to maintain a position of leadership in an ever increasing competitive, global economy it must produce qualified STEM applicants. Presently, the U.S. is not succeeding in this arena. In order to meet the deficit, minorities and women must be recruited into STEM programs, and supported emotionally and mentally to prevent attrition. Many science institutions, foundations, and associations support open-inquiry research in schools to help alleviate this problem. Cognitive apprenticeship methodology (Collins, et al., 1989) is one conceptual framework for implementing open-inquiry research. The two projects discussed in this dissertation are examples of open-inquiry research that seemed to allowed remote, rural students to overcome their cultural borders, their lack of academic preparation, and their inexperience in authentic research to be successful in post-secondary STEM majors.

References

Aikenhead, G. (1996). Science education: Border crossing into the subculture of science. *Studies in Science Education, 26,* 1-52.

Aikenhead, G. (1998). Many students cross cultural borders to learn science: Implications for teaching. *Australian Science Teachers' Journal, 44*(4), 9-12.

American Association for the Advancement of Science. (2017). *What issues arise with inquiry learning and teaching? part 3.* Retrieved from AAAS: http://ehrweb pdf.aaas. org. pdf.aaas.org.PDF/inquirypart3.pdf

Astin, A. W., & Astin, H. S. (1992). *Undergraduate science education: The impact of different college environments on the educational pipeline in the sciences.* Los Angeles, CA: Higher Education Research Institute at UCLA.

Atwater, M. (1996). Social constructivism: Infusion into the multicultural science education research agenda. *Journal of Research in Science Teaching, 33*(8), 821-837.

Betz, N. (1978). Prevalence, distribution, and correlates of math anxiety in college students. *Journal of Counseling Psychology, 25*(5), 441-448.

Bouta, H., & Paraskeva, F. (2013). The cognitive apprenticeship theory for the teaching of mathematics in an online 3D virtual environment. *International Journal of Mathematical Education in Science and Technology, 44*(2), 159-178.

Bradshaw, S., Chamberlain, V., Clark, R., Gillespie, C., Good, J., Hunter, C., . . . Whitlow, E. (2016). The preliminary survey of *Wolbachia* infected insects in the [redacted] Oklahoma Area. *National High School Journal of Science,* 1-10.

Brown, J., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Business Roundtable. (2008). *Tapping America's potential: The education for innovation initiative-Gaining momentum, losing ground.* Washington, DC: author.

Carnevale, A., Smith, N., & Melton, M. (2014). *STEM state-level analysis.* Washington, DC: Georgetown University Center on Education and the Workforce.

Charney, J., Hmelo-Silver, C., Sofer, W., Neigeborn, L., Coletta, S., & Nemeroff, M. (2007). Cognitive apprenticeship in science through imersion in laboratory practices. *International Journal of Science Education, 29*(2), 195-213.

Chiu, M., Chou, C., & Liu, C. (2002). Dynamic processes of conceptual change: analysis of constructing mental models of chemical equilibrium. *Journal of Research in Science Teaching, 29*(8), 688-712.

Collins, A. (2006). Cognitive apprenticeship. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 47-60). New York: Cambridge University Press.

Collins, A., Brown, J., & Holum, A. (1991a). Cognitive apprenticeship: Making thinking visible. *American Educator, 15*(3), 6-11.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale: Lawrence Erlbaum Associates.

Collins, A., Hawkins, J., & Carver, S. (1991b). *Cognitive apprenticeship for disadvantaged students.* Washington, DC: Center for Technology in Education.

Committee on Science and Technology. (2007). *Improving the laboratory experience for America's high school students.* Washington D.C.: U.S. Government Printing Office

Costa, B. (1995). When science is "another world": Relationships between worlds of family, friends, school, and science. *Science Education, 79*(3), 313-333.

Crawford, B. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37*(9), 915-937.

Creswell, J. (2013). *Qualitative Inquiry and Research Design: choosing among five approaches.* London: Sage.

Dewey, J. (1907/2009). *The child and the curriculum and the school and society.* ReadaClassic.com

Dewey, J. (1897). My pedagogic creed. *The School Journal*, 77-80.

Dewey, J. (1938/1997). *Experience and Education.* New York: Kappa Delta Pi.

Dewey, J. (1945). Method in science teaching. *Science Education, 29*(3), 119-123.

Dika, S., & D'Amico, M. (2016). Early experiences and integration in the persistence of first-generation college students in STEM and non-STEM majors. *Journal of Research in Science Teaching, 53*(3), 368-383.

Dimitriadis, G., & Kamberelis, G. (2006). *Theory for education.* New York: Routledge, Taylor & Francis Group.

Educational Policies Commission. (1961). *The central purpose of American education.* Washington, DC: National Education Association.

Glassman, M. (2001). Dewey and Vygotsky: Society, experience, and inquiry in Educational Practice. *Edcational Researcher, 30*(4), 3-14.

Golafshani, N. (2003). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*, 8(4), 597-606.

Goldman, R., Hewitt, B., & Newlin, B. (1976). The scholastic aptitude test: explains" why college men major in science more often than college women". *Journal of Counseling Psychology, 23*(1), 50-53.

Gordin, D., & Pea, R. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences*, 391-450.

Graham, M., Frederick, J., Byars-Winston, A., Hunter, A., & Handelsman, J. (2013). Increasing persistence of college students in STEM. *Science Education, 341*, 1455-1456.

Grant, C. & Osanloo, A. (2014). Understanding, selecting, and integrating a theoretical framework in dissertation research: creating the blueprint for you house. DOI: 10.5929/2014.4.2.9

Hackett, G., & Betz, N. (1981). A self-efficacy approach to the career development of women. *Journal of Vocational Behavior, 18*, 326-339.

Hall, P. (2017, December 10). High School Principal. (N. Rech, Interviewer)

Hill, C. (2015). Solving the equation: the variables for women's success in engineering and computing. American Association for University Women. https://www.aauw.org/research/solving-the-equation/

Johnson, A. (2017, December 10). High School Counselor. (N. Rech, Interviewer).

Kelley, T., & Knowles, G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(11), 1-20.

Korn, M. (2015, January). *Number of college students pursuing science, engineering stagnates*. *The Wall Street Journa*l. Retrieved from http://www.wsj.com/articles/number-of-college-students-pursuing-science-engineering-stagnates-1422334862

Krajcik, J., Blumenfeld, P., Marx, R., Bass, K., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *The Journal of the Learning Sciences, 7*(3 & 4), 313-350.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* New York: Cambridge University Press.

Miller, J. (2004). Public understanding of, and attitudes toward, science research. *Public understanding of science*, 13(3), 273-294.

Morrow, S. (2005). Quality and trustworthiness in qualitative research in counseling psychology. *Journal of Counseling Psychology*, 52(2), 250-260.

Moustakas, C. (1994). *Phenomenological research methods*. Thousand Oaks, CA: Sage.

National Academies of Sciences, Engineering, and Medicine. (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts.* Washington, DC: The National Academies Press. https://doi.org/10.17226/21836.

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. (2011). *Expanding underrepresented minority participation: America's science and technology talent at the crossroads.* Washington, DC: The National Academies Press. https://doi.org/10.17226/12984.

National Center for Education Statistics. (2014). *STEM attrition: College students' paths into and out of stem fields - Statistical analysis report.* Washington, DC: U.S. Department of Education.

National Center for Education Statistics. (2015, July). *The condition of education*. Retrieved from http://nces.ed.gov/programs/coe/indicator_tva.asp

National Commission on Excellence on Education. (1983). *A nation at risk: The imperative for educational reform.* Washington, DC: U. S. Department of Education.

National Science Board. (2010). *Preparing the next generation of STEM innovators: Identifying and developing our nation's human capital.* Washington, DC: National Science Foundation.

National Science Board. (2012). *Science and engineering indicators 2012.* Arlington, VA: National Science Foundation.

National Science Board. (2015). *Revisiting the STEM workforce: A companion to science and engineering indicators 2014.* Washington, DC: National Science Foundation.

Oklahoma State Department of Education. (2015). *Average state ACT scores by school districts.* Retrieved from www.ok.gov/sde/sites/ok.gov.sde/files/ACT-07.pdf

Ortiz, A., & Sriraman, V. (2015). Exploring faculty insights into why undergraduate college students leave STEM fields of study-a three part organiztional self-study. *American Journal of Engineering Education*, *6*(1), 43-60.

Phelan, P., Davidson, A., & Cao, H. (1991). Students' multiple worlds: Negotiating the boundaries of family, peer, and school cultures. *Anthropology and Education Quarterly, 22*(3), 3-44.

President's Council of Advisors on Science and Technology. (2012). *Report to the President: Engage to excell-producing one million additional college graduates with degrees in science, technology, engineering, and mathematics.* Washington, DC: Executive Office of the President.

Putica, K., & Trivic, D. (2016). Cognitive apprenticeship as a vehicle for enhancing the understanding and funtionalization of organic chemistry knowledge. *The Royal Society of Chemistry, 17*, 172-196.

Reason, R. (2009). An examination of persistance research through the lens of a conprehensive conceptual framework. *Journal of College Student Development, 50*(6), 659-682.

Roth, W. M. (1991). *Aspects of cognitive apprenticeship in science teaching.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Lake Geneva, WI.

Sells, L. (1973). High school mathematics as the critical filter in the job market. *Proceedings of the Conference on Minority Graduate Education at the University of California* (pp. 1-6). Berkeley, CA: University of California.

Seng, S. (1997). Zone of proximal development and the world of the child. *Educational Research Association Conference* (pp. 2-15). Singapore: Educational Resources Information Center.

Shotter, J. (1989). Vygotsky's psychology: Joint activity in a developmental zone. *New Ideas in Psychology, 7*(2), 185-204.

Sin, C. (2015). Student-centered learning and disciplinary enculturation: An exploration through physics. *Educational Studies, 41*(4), 351-368.

Toven-Lindsey, B., Levis-Fitzgerald, M., Barber, P., & Hasson, T. (2015). Increasing persistence in undergraduate science majors: A model for institutional support of underrepresented students. *Life Science Education, 14*(2), 1-14.

Trent, W. & Baber, L. (2015). Increasing and supporting underrepresented populationsin STEM fields. Bureau of Education Research. University of Illinois.

Tsai, C., Jack, B., Huang, T., & Yang, J. (2012). Using the cognitive apprenticeship web-based argumentation system to improve argumentation instruction. *Journal of Science Education and Technology*, *12*, 476-486.

U.S. Census Bureau. (2014). *Fact finder census government*. Retrieved from https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml

U.S. Department of Defense. (2014). *Ace the ASVAB.* Washington, DC: U.S. Department of Defense. Retrieved from www.military.com/jion-armed-forces/asvab/

Vandervoort, F. (1983). What would John Dewey say about science teaching today? *The American Biology Teacher, 45*(1), 38-41.

Vygotsky, L. S. (1978). *Mind in society - The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Zion M. & Mendelovici, R. (2012). Moving from structured to open inquiry: challenges and limits. Science Education International, 23(4), 383-399.

Appendix A: IRB Letter of Approval

The UNIVERSITY of OKLAHOMA

Institutional Review Board for the Protection of Human Subjects

Approval of Initial Submission – Expedited Review – AP01

Date: December 19, 2017

IRB#: 8668

Principal Investigator: Niccole Dorrett Rech

Approval Date: 12/19/2017
Expiration Date: 11/30/2018

Study Title: Which Elements of Cognitive Apprenticeship Methodology are Most Effective in Improving STEM Self-Efficacy of Remote, Rural High School Students?

Expedited Category: 6 & 7

Collection/Use of PHI: No

On behalf of the Institutional Review Board (IRB), I have reviewed and granted expedited approval of the above-referenced research study. To view the documents approved for this submission, open this study from the *My Studies* option, go to *Submission History*, go to *Completed Submissions* tab and then click the *Details* icon.

As principal investigator of this research study, you are responsible to:

- Conduct the research study in a manner consistent with the requirements of the IRB and federal regulations 45 CFR 46.
- Obtain informed consent and research privacy authorization using the currently approved, stamped forms and retain all original, signed forms, if applicable.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB policy.
- Maintain accurate and complete study records for evaluation by the HRPP Quality Improvement Program and, if applicable, inspection by regulatory agencies and/or the study sponsor.
- Promptly submit continuing review documents to the IRB upon notification approximately 60 days prior to the expiration date indicated above.
- Submit a final closure report at the completion of the project.

If you have questions about this notification or using iRIS, contact the IRB @ 405-325-8110 or irb@ou.edu.

Cordially,

Fred Beard, Ph.D.
Vice Chair, Institutional Review Board

Appendix B: Informed Consent

Signed Consent to Participate in Research

Would you like to be involved in research at the University of Oklahoma?

I am Niccole D. Rech from the Instructional Leadership and Academic Curriculum Department and I invite you to participate in my research project entitled *A Phenomenological Study of Rural, High School Students' Experiences in Cognitive Apprenticeship Methodology in an Upper-Level Biology Class.* This research is being conducted at [redacted], Oklahoma. You were selected as a possible participant because you were a participant in either the rhizobia project or the *Wolbachia* project, or both. The projects were taught with cognitive apprenticeship methodology. You must be at least 18 years of age to participate in this study.

Please read this document and contact me to ask any questions that you may have BEFORE agreeing to take part in my research.

What is the purpose of this research? The purpose of this research is to discover the lived experiences of students that participated in these projects which were both taught with cognitive apprenticeship methods.

How many participants will be in this research? About five to seven people will take part in this research.

What will I be asked to do? If you agree to be in this research, you will be asked to be interviewed about your experiences and how they affected you. The interview will last about 45 minutes. If more information is needed, a second shorted interview will take place.

How long will this take? Your participation will take about 45 minutes. If more information is needed, a second shorter interview, maybe 15 to 20 minutes will take place.

What are the risks and/or benefits if I participate? There are no risks and no benefits from being in this research. The benefits are knowing that you potentially helped or motivated other educators to use this methodology in their science programs.

Will I be compensated for participating? You will not be reimbursed for your time and participation in this research

Who will see my information? In research reports, there will be no information that will make it possible to identify you. Research records will be stored securely and only approved researchers and the OU Institutional Review Board will have access to the records.

You have the right to access the research data that has been collected about you as a part of this research. However, you may not have access to this information until the entire research has completely finished and you consent to this temporary restriction.

Do I have to participate? No. If you do not participate, you will not be penalized or lose benefits or services unrelated to the research. If you decide to participate, you don't have to answer any question and can stop participating at any time.

Will my identity be anonymous or confidential? Your name will not be retained or linked with your responses. The data you provide will be retained in an anonymous form unless you specifically agree for data retention or retention of contact information at the end of the research. Please check all of the options that you agree to:

I agree to being quoted directly. ___ Yes ___ No

I agree to have my name reported with quoted material. ___Yes ___ No

I agree for the researcher to use my data in future studies. ___Yes ___ No

Audio Recording of Research Activities To assist with accurate recording of your responses, interviews may be recorded on an audio recording device. You have the right to refuse to allow such recording without penalty.

I consent to audio recording. ___Yes ___ No

Will I be contacted again? The researcher would like to contact you again to recruit you into this research or to gather additional information.

_____ I give my permission for the researcher to contact me in the future.

_____ I do not wish to be contacted by the researcher again.

Who do I contact with questions, concerns or complaints? If you have questions, concerns or complaints about the research or have experienced a research-related injury, contact Mrs. Niccole D. Rech at (903)-272-0131 or ndrech@hotmail.com. You may also contact Dr. Timothy Al Laubach at (405) 325-1498 or laubach@ou.com.

You can also contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu if you have questions about your rights as a research participant, concerns, or complaints about the research and wish to talk to someone other than the researcher(s) or if you cannot reach the researcher(s).

You will be given a copy of this document for your records. By providing information to the researcher(s), I am agreeing to participate in this research*.*

Participant Signature	Print Name	Date
Signature of Researcher Obtaining Consent	Print Name	Date
Signature of Witness (if applicable)	Print Name	Date

Appendix C: Interview Questions

Semi-Structured Interview Question Clusters

Cluster One: Present Situation
How have you been, and what are you doing now?
If you are at a university, what is your major, and what university are you attending?
Did you feel prepared for your courses?
Were you pleased with your courses?
Did you have any scholarships going into university?
If you are working, what are you doing?
Cluster Two: Rhizobia Project
This part of the interview is about the Rhizobia Project. I want you to take a few minutes and think about the project, your experiences and feelings while you were in the project.
What do you remember about those experiences and how did they affect you?
What affect did they have on your technical skill level? Confidence?
How did the exposure to a university research lab affect you?
What were your feelings as you worked on the project?
What skills did you learn?
What did you learn about rhizobia?
Can you remember any of the teaching techniques used?
Did this experience have any influence on your future aspirations?
Cluster Three: *Wolbachia* Project
This part of the interview is about the *Wolbachia* Project.
What do you remember about your experiences as you worked on the project?
How many students were involved?
What skills did you learn and what responsibilities did you have?
How did you learn these skills?
Did all of the students have the same amount of responsibilities?
If not, how did that make you feel?
Were the skills difficult?
What about the cognitive part of the project?
You had to read scientific research papers about *Wolbachia*. Was that difficult?
Did you have to explain the information?
What specifically helped you understand the information?
Have any of these experiences helped you in your college courses? Which ones, and how did they help you?
Did they have any influence on your choice of a major?
Have you benefitted from these programs, if so how?

Appendix D: Students' Journal Article

The Preliminary Survey of *Wolbachia* Infected Insects in the [redacted], Oklahoma Area

Figure 1. *Polistes carolina* (L.), red paper wasp infected with *Wolbachia*

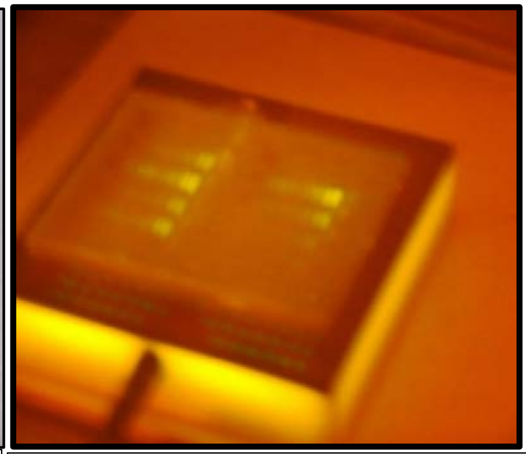

Figure 2. Electrophoresis gel (L to R) positive control, 3 infected *Polistes carolina* (L.)

Abstract

Wolbachia, a genus of bacteria that infects a wide variety of arthropods, is in the Rickettsia family. *Wolbachia* is an endosymbiont and has the potential to inhibit the transmission of some diseases like, Malaria, Zika virus, Dengue fever, West Nile Virus and Chikungunya. It is also known to affect the reproductive process of some species of insects through feminization, cytoplasmic incompatibility, horizontal and vertical transmission, and parthenogenesis. During the spring semester of 2016, the advanced biology students at Fort Towson High School converged to collect, photograph, identify and test local insects for *Wolbachia*. The students have collected 37 insects in the Fort Towson area. In order to test the insects for *Wolbachia*, DNA was extracted, then amplified with PCR and run through an electrophoresis gel. Using the restriction enzyme TE/Rnase, *Wolbachia* is identified at 438 kbp and insect DNA is identified at 709 kbp. Forty-three percent of these insects were infected with *Wolbachia.*

Background

[redacted] is a small, remote rural town, with a population of 505, nestled in southeastern Oklahoma[24]. Most of the town is a collection of small ranches and farms; there is also a lake, Raymond Gary that is 390 square acres. Besides the lake, there are multiple small farm ponds where mosquitoes can breed. Mosquitoes are vectors that transfer pathogenic viruses, bacteria, and protists that cause diseases. The mosquitoes transfer the pathogens from one area to another, without getting the disease themselves. They carry infectious agents for many major diseases that have a strong impact on the human population such as Dengue Fever, Malaria, Chikungunya, West Nile virus and Zika virus[4].

Dengue Fever occurs in tropical and subtropical areas of the world[2,14]. A mild case of Dengue Fever causes high fever, rash, and muscle and joint pain, while a severe case of Dengue fever causes severe bleeding, a sudden drop in blood pressure and death[14]. Malaria, another tropical disease transmitted by mosquitoes, is also passed from mother to offspring during birth[4]. Chikungunya, another disease caused by mosquitoes, causes fever and joint pain[4].

While all of the above diseases impact the global population, only two of the diseases, the Zika and West Nile viruses impact the Oklahoman population[15]. West Nile Virus was introduced into the United States in 1999. Since then, it has spread throughout the entire continental US. Its relationship with *Wolbachia* is unique. In the presence of *Wolbachia*, the production of West Nile Virus genomic RNA increases, however the transmission of the virus decreases[10]. The symptoms of Zika Virus are very similar to Dengue[16] and Chikungunya. The disease is very mild with symptoms lasting for several days[4]. However, Zika virus can cause serious birth defects, such as microcephaly, if an infected mosquito bites and infects a pregnant mother[4].

Wolbachia inhibits these diseases by preventing their transmission. Some mosquito species cannot be infected naturally, so scientists are having to manually infect them. Once they are infected, the mosquitoes are turned loose into communities in hopes that it will slow the spread of these diseases[15].

The Rickettsial bacteria, *Wolbachia*, are found commonly in the reproductive tissues of its hosts. *Wolbachia* causes vertical and horizontal transmission, feminization, cytoplasmic incompatibility, and parthenogenesis. Vertical transmission is the transfer of this bacterium from mother to child[27]. Horizontal transmission is the unexpected transfer of genes between species[20]. *Wolbachia* usually undergoes vertical transmission, through the maternal line of its host population [3,25]. The ability of *Wolbachia* to invade host populations cannot account for the high number of arthropod species that are infected. Although, the reproduction alteration of the host can explain how *Wolbachia* invades new host, but not how *Wolbachia* reaches these new host[25]. Molecular phylogenetic analysis[18] suggests that the *Wolbachia* common ancestor evolved between 80 and 100 million years ago[17]. The evolution of an arthropod common ancestor occurred at least 200 million years ago. As *Wolbachia* isotypes are in a wide variety of arthropods, this observation leads to the conclusion that *Wolbachia* undergoes horizontal transmission as well as vertical transmission[6].

Vertically transmitted facultative bacterial endosymbionts are common in invertebrates, and affect traits such as mode of sexual reproduction, speciation, and susceptibility to pathogens[1]. Vertical transmission could cause either the endosymbiotic relationship to be essential for the host to survive, or that the endosymbiont could cause the health of its host[1].

It was suggested that *Wolbachia* can be passed to parasitoids through horizontal transmission with high frequencies in 1999[25]. However, according to recent research, scientist tried to contest this theory by saying, horizontal transmission is rarely found and rather challenging to document[1]. Scientist have said that the mouthparts of a wasp parasitoid becomes contaminated with *Wolbachia* when the wasp feeds on a *Wolbachia* infected whitefly. *Wolbachia* needs a vertical transmission that is stable after horizontal transmission to infect a new host[6]. There are many reasons to think that a stable vertical transmission may not be easy to establish in a new host[6].

The bacteria *Wolbachia* causes a large range of effects on its hosts: it is able to kill males, turn them to females, or sterilize uninfected females or also behave as a mutualistic symbiont. Being present in numerous arthropod and nematode species this symbiont is bringing attention to developmental and evolutionary biologists[5,26].

Wolbachia must interact with the host sex determination system. Male-killing bacteria has to either detect host sex and then kill males or interfere directly with sex determination to produce male death[5]. In Coleoptera, Lepidoptera, and Diptera, *Wolbachia* kills the sons of infected female because *Wolbachia* is only transmitted through female insects[5]. The sex-determination system is at the heart of the interaction between the host and reproductive parasites. If parasite popularity is high, then the selection pressure for modifiers of sex determination that circumvent the action of the *Wolbachia* will be very strong. *Wolbachia* can also provide material for the evolutionary novelty, by contributing host functions, or even transferring genes to the nucleus[5].

As a frequent manipulation of host reproductive biology, *Wolbachia* must interact with the host sex-determination system. Given that death occurs during embryogenesis, therefore, they must interact with upstream components of sex-determining pathways[13].

In some insect species, males have one set of chromosomes, fertilized eggs are females those that are unfertilized become males. This bacterium wipes out all males; females that are infected with *Wolbachia* produce unfertilized eggs either copy chromosomes without dividing or go through normal cell division[22]. This is referred to as parthenogenesis. This bacterium seems able to shape the sex determination directly in insects[22]. It is not fully known what *Wolbachia* does, but if antibiotics are given to the insects during development, females will develop normally, but the males that had originally started out as females, will be caught somewhere between the two sexes, this is called feminization[22].

In the 1950s it was discovered that certain intraspecific crosses within *Culex* mosquitoes, were unable to be cultured because they produced very few or no offspring[26,27]. There were many eggs laid by all combinations of insemination, but only certain crosses hatched[11,12]. A few eggs were considered sterile. Those that hatched died immediately, even with careful raising. The sterile eggs contained embryos. Upon dissecting a female, the eggs that did not show any embryo were produced by an inseminated female[11,19]. This manifestation was called cytoplasmic incompatibility[27].

Wolbachia was discovered in 1924 by Hertig and Wolbach[26,28] during a survey on micro-organisms known as ‘Rickettsia’. Noller discovered a Rickettsia embedded in the yeast layer of the “sucking stomach” of a *Culex pipiens* mosquito in 1920[8,9,19]. Schaudinn (1904) found that these yeasts were constantly inhabiting the “sucking stomach” in the *Culex pipiens*[21] and certain different mosquitoes. In 1936, *Wolbachia* was named after Wolbach whom was one of the identifiers [8].

Methods and Materials:

Once the insect is captured, it is immediately frozen to prevent the degradation of the DNA. Afterwards, the insects were identified, photographed, and drawn before extracting the DNA. The insects were placed back in the freezer whenever possible.

Insect Identification

Insects are identified by both common name and scientific name. Scientific names are used throughout the world, and every known animal taxon has a scientific name unique to it. Common names are vernacular names, and they are usually less precise than scientific names. The scientific naming of animals follows certain rules, outlined in the *International Code of Zoological*[23]. All insects are in Kingdom Animalia, Phylum Arthropoda, and Class Insecta. In the project, the insects were identified at four levels: Order, Family, Genus, and Species. There are five common ways in which an insect may identified: (1) by having it identified by an expert, (2) by comparing it to with labeled specimens in a collection, (3) by comparing it with pictures, (4) by comparing it with descriptions, (5) by using analytical key. In the project, the combination of last three procedures were used. Comparing the insects with pictures need the help of the Internet, pictures used for comparison came from Universities and Government Websites. Description and using analytical keys came from *The Study of Insect*[23]. Beside the insects' identification, diet, habitat and life cycle were also recorded. After identification, insects are photographed and drawn.

Extracting DNA:

Obtain a clean 1.5 mL microfuge tube and label the tube with the insect identification number. Remove the insect from the freezer. Obtain a ruler and measure the length of the insect's abdomen. If the abdomen is less than 2.0 mm long and 2.0 mm wide, you can use the entire abdomen. If the abdomen is larger than 2.0 mm long and 2 mm wide, cut a 2.0 mm long section from the most posterior end of the abdomen. If the entire insect is smaller than 2.0 mm, use the whole insect. Place the insect or piece of insect into the labeled, cleaned microfuge tube. The piece of insect should sit about halfway to the 0.1 mL mark. Add 200.0 microliters of lysis buffer.

Macerate the insect by twisting a small, plastic micro-pestle for at least one minute, or until only small bits of chitinous exoskeleton remain. You must use considerable downward and rotating force to adequately macerate the insect tissue. Once the insect is sufficiently macerated, add 800.0 microliters of lysis buffer. Make sure the contents of the tube are thoroughly mixed, by vortexing the tube. Slide a cap lock onto your tube and place it in the 99.0-degree Celsius heat block, or water bath, for 5.0 minutes. The cap locks prevent tubes from popping open due to vapor pressure. After heating, open the tube briefly to release pressure, then close. Vortex, or shake tube to mix, and place in a balanced centrifuge. Centrifuge for 5.0 minutes, at 10,000g.

Obtain a second clean 1.5 mL microfuge tube. Label the tube with the insect identification number. Retrieve the tube from the centrifuge. There may be a noticeable pellet at the bottom of the tube. Without disturbing the pellet, withdraw 400.0 microliters of the liquid from the centrifuge tube, and transfer it to the new tube. Discard the old tube containing the pellet. Add 40.0 microliters of 5.0 molar NaCl to the tube containing 400.0 microliters of the liquid you removed. Shake the tube a few times to mix. Incubate on ice for 5-10 minutes.

Obtain a third clean 1.5 mL microfuge tube. Label the tube with "DNA" and the identification number. Retrieve your tube from the centrifuge. There may be a noticeable pellet at the bottom of the tube. Without disturbing the pellet withdraw 300.0

microliters from the top of the tube. Be sure not to take anything from the bottom of the tube. Add 400.0 microliters isopropanol to your new tube of the transferred liquid. Mix contents by inverting your tube several times, or vortex for a few seconds.

Place the tube with the isopropanol mixture in a balanced centrifuge. Orient the hinge of the tube to point outward and away from the middle of the centrifuge. Spin at top speed for 5.0 minutes. Retrieve the tube from the centrifuge. Carefully pour the liquid out of the tube. Tap the mouth of the tube lightly onto a clean paper towel to remove the liquid on the top of the tube. Spin quickly again in the centrifuge to pool the rest of the liquid and use a pipette to completely remove all of the supernatant. Aim the tip away from the pellet to remove the liquid. Air Dry the pellet for about 5-10 minutes to evaporate any remaining isopropanol.

Keep the cap open. Add 200.0 microliters of TE\RNase Buffer to the tube. Scrape the side of the tube where the pellet is, with the tip to facilitate resuspension. Pipette up and down several times to collect DNA accumulated on the area underneath the hinge. Observe the DNA. If it is clear, proceed to the next step. If it is cloudy, there is a lot of debris so add another 200.0 microliter of TE\RNase. After resuspension place your tube in the centrifuge. Balance and spin the tubes for 1.0 minute. Freeze DNA until ready to proceed to PCR. Clean materials used.

Procedure for PCR:

Obtain a PCR tube containing a PCR bead. Tap tube gently on counter to move bead to bottom of tube. The PCR bead contains the DNA polymerase, dNTPs and buffer component. Using a permanent marker, label the tube on the lid with the identification number. Add 20.0 microliters to your tube, close lid, and tap gently to dissolve the bead. Add 5.0 microliters of extracted insect DNA. Close tube tightly and tap gently to mix components in your tube. Place the tubes into the thermocycler and start the PCR cycling protocol; 95 degrees Celsius for 2.0 minutes, 94.0 degrees Celsius for 30.0 seconds, 55.0 degrees Celsius for 45.0 seconds, 72.0 degrees Celsius for 1.0 minute, 72.0 degrees Celsius for 10.0 minutes, 4.0 degrees Celsius for infinity. The program can be stopped any time during this last hold and tubes can be removed.

Electrophoresis Procedure:

Following PCR, electrophoresis is performed in order to separate the insect DNA from the *Wolbachia* DNA. The first step in beginning electrophoresis is to add the SYBR Safe Green Dye to the PCR tube containing the insect DNA. Next a 1.2% agarose gel is placed into the tray which is then placed in the electrophoresis chamber. A buffer, in this case LB1X, is then poured into the chamber to allow the electricity to flow from the connected power source throughout the buffer. Once the LB1X is poured, the insect DNA and the DNA ladder are loaded into the gel. Electrophoresis is then run for approximately 30 minutes.

Results

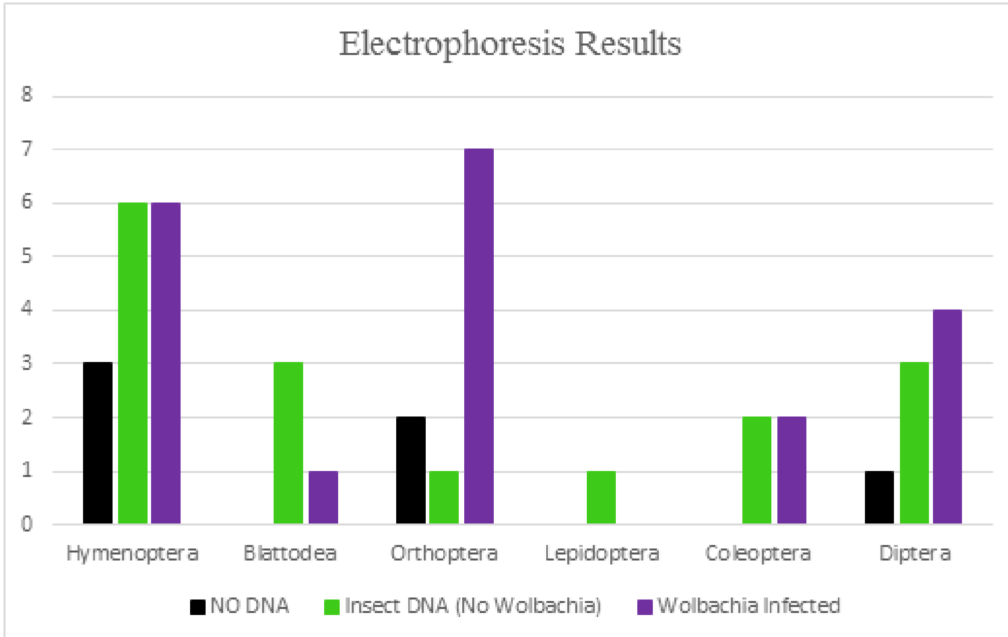

Figure 3. DNA results by Insect Orders

Table 1: Electrophoresis Results

12-4-15	1-12-16	1-27-16	2-11-16	3-9-16	4-12-16	4-13-16
Field Cricket	Conehead Grasshopper	House Fly	Camel Cricket; Bald Faced Hornet	Red Paper Wasp	Asian Lady Beetle	
	Cockroach	Little Black Ant	Camel Cricket	Field Cricket	Red Paper Wasp	Red Paper Wasp
	June Bug	Red Paper Wasp	Katydid	Field Cricket	Red Paper Wasp	House Fly
	Yellowjacket / Paper Wasp	Bi- Colored Red Harvester Ant	Katydid	Field Cricket	Red Paper Wasp	Positive Control

						Infected Fruit Fly
	Red Wasp/ Paper Wasp	European Corn Borer (Moth)	Field Cricket	Little Black Ant	Positive Control Infected Fruit Fly	
	Lady Bug	German Cockroach	Oriental Cockroach	Little Black Ant		
	House Fly	Cockroach	Darkling Beetle	Little Black Ant		
	Honey Bee	Positive Control Infected Fruit Fly	Positive Control Infected Fruit fly	Positive Control Infected Fruit Fly		Key Purple – Positive Green- Negative Black – no DNA

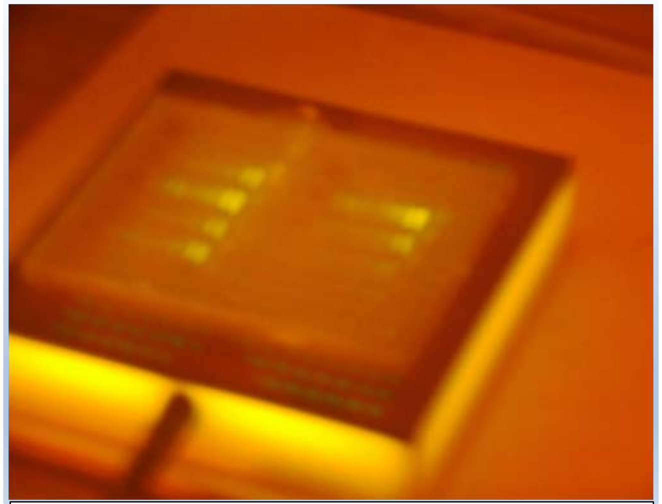

Figure 4. Electrophoresis using the transilluminator

Discussion:

As shown above (table 1), groups of insects have been tested for *Wolbachia* on seven different occasions. The first test was performed at OCCC (Oklahoma City Community College) under the guidance of professors who had previously been testing insects for *Wolbachia*. The following six tests were all performed in our lab at [redacted] High School. The first two tests were run using a Methylene Blue procedure. While using the Methylene Blue procedure, results always came up showing only insect DNA and no *Wolbachia,* even when a positive control was included. Due to a lack of clear results we then changed to using a SYBR Safe Green Dye, and a UV Transilluminator. Electrophoresis was performed on a total of 37 insects and 16 of those were infected with *Wolbachia*.

As shown in the graph above (figure 3), insects were captured from 6 different orders. Four insects of the order Blattodea were captured, of the 4, 1 was infected with *Wolbachia*. In the order Coleoptera 2 of the 4 captured tested positive for *Wolbachia*. In the case of Diptera, an infected *Drosophila* given to us by OCCC was used as a positive control on 5 separate occasions. However, for the other 3 occasions when testing insects from the order Diptera, house flies caught in the Fort Towson area were used. Errors occurred in the testing of 2 of the positive control fruit flies, in one case the insects' DNA went through a hole in the bottom of the gel, and in the other case the methylene blue procedure was not providing clear enough bands to see the *Wolbachia.* Of the three wild house flies only one was infected. There were fifteen insects belonging to the order Hymenoptera captured, and of those fifteen, six were infected with *Wolbachia.* A single European corn borer moth from the order Lepidoptera was captured and tested, with the moth testing negative for *Wolbachia*. Ten insects from the order Orthoptera were captured and tested. Of those ten, 7 were infected, 1 was not infected, and there was an error in the testing of the other 2. Based on our results in this experiment it is hypothesized that insects in the order Orthoptera are more susceptible to *Wolbachia* than other orders in this area.

The first column on the table shows the results of a field cricket that was tested at OCCC using their equipment. The next two columns were performed in the lab at Fort Towson High School using a Mini PCR and a methylene blue procedure. Due to two consecutive tests lacking clear electrophoresis results using the methylene blue procedure, the procedure was changed to one that uses a SYBR safe green dye and a Pearl Blue Biotech UV Transilluminator, (shown in figure 4), for the remainder of the project. Beginning with the insects from the sixth column, a 1.2% agarose gel was used as opposed to the previously used 2.0% gel. An important finding during this experiment was that every insect tested, without error, since changing to the SYBR safe green dye and transilluminator, has tested positive for *Wolbachia*. In the 4th column there was an error in loading the SYBR safe green dye into the two katydid's DNA, causing their electrophoresis results to be unclear.

Conclusion:

Due to not being able to test many insects in each order, further research is required. The primary reason certain insects could not be collected for testing is the season. It was winter and early spring so not many insects could be found in order to be tested. Insects such as mosquitoes and dragonflies would not be around due to the cold weather conditions. Most insects were collected from the same general area in [redacted] thus not providing many results for all of the [redacted] area. Also, in future research of *Wolbachia* it could prove beneficial to obtain the equipment needed to differentiate between the different strains of *Wolbachia*.

Acknowledgement

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References

1. Ahmed, M., et al. "The Intracellular Bacterium Wolbachia Uses Parasitoid Wasps as Phoretic Vectors for Efficient Horizontal Transmission." *Pathogens* (2015): 1-19.
2. 2. Andre, A., et al. "The Role of Endosymbiotic Wolbachia Bacteria in the Pathogenesis of River Blindness." *Science* 295 (2002): 1892-1895.
3. Bordenstein, S., O'Hara F. and J. Werren. "Wolbachia induced incompatibility precedes other hybrid incompibilities in Nasonia." *Nature* 409 (2001): 707-710. Letter to Nature.
4. Center for Disease Control. *Center for Disease Control*. 2016. http://www.cdc.gov/media/index.html. 26 April 2016.
5. Charlat, S., G. Hurst and H. Mercot. "Evolutionary consequences of wolbachia infections." *Treands in Genetics* 19.4 (2003): 217-223.
6. Health Line. *Health Line Malaria*. 2015. http://www.healthline.com/health/malaria. 26 April 2016.
7. Heath, B., et al. "Horizontal transfer of Wolbachia between phylogenetically distant insect species by a naturally occurring mechanism." *Current Biology* 25.9 (1999): 313-316.
8. Hertig, M. and S. Wolbach. "Studies on Rickettsia-like microorganisms in insects." *The Journal of Medical Research* 44 (1924): 329-374.
9. Hertig, M. "The Reckettsia, Wolbachia pipientis and Associated Inclusion of the Mosquito, Culex pipiens." *Parasitology* 28.4 (1936): 453-486.
10. Hussain, M., et al. "Effect of Wolbachia on Replication of West Nile Virus in a Mosquito Cell Line and Adult Mosquitoes." *Journal of Virology* 87.2 (2013): 851-858.
11. Laven, H. "Crossing Experiments with Culex Strains." *Evolution* 5.4 (1951): 370-375.
12. —. "Speciation by cytoplasmic isolation in Culex pipiens complex." *Cold Spring Harbor symposia on quantitative biology*. New York: Cold Spring Harbor Symposia, 1959. 166-173.
13. Mains, J., et al. "Population impacts of Wolbachia on Ades albopictus." *Ecological Applications* 23.2 (2013): 493-501.
14. Mayo Clinic. *Mayo Clinic Dengue Fever*. 2014. http://www.mayoclinic.org/diseases-conditions/dengue-fever/basics/definition/con-20032868. 26 April 2016.
15. Oklahoma Department of Health . *Oklahoma Department of Health - Zika Virus*. 2016. www.ok.gov/health/Disease,_Prevention,_Preparedness/Acute_Disease_Service/Disease_Information/Zika_Virus.html. 26 April 2016.

16. O'Neill, S. "How a Tiny Bacterium Called Wolbachia Could Defeat Dengue." *Health* (2015): 1-12.
17. Pintureau, B., et al. "Addition of wsp Sequences to the Wolbachia Phylogenetic Tree and Stability of the Classification." *Journal of Molecular Evolution* 51 (2000): 374-377.
18. Rolain, J., et al. "Molecular Detection of Bartonella quintana, B. koehlerae, B. henselae, B. clarridgeiae, Rickettsia felis, and Wolbachia pipientis in Cat Fleas, France." *Research* 9.3 (2003): 338-342.
19. Schaudinn, F. "Generations und Wirtswechel bei Trypanosoma und Spirochate." *Arbeiten aus dem Kaiserlichen Gesundheitsamte* 20 (1904): 387-440.
20. Schneider, S. and J. Thomas. "Accidental Genetic Engineers: Howizontal Sequence transfer from Parasitoid Wasps to their Lepidopteran Hosts." *Plus One* 9.10 (2014): 1-13.
21. Sikora, H. "Beobachtungen an Rickettsien." *Archiv fur Schiffs-und Topen-Hygiene* 24 (1920): 346-353.
22. Timmer, J. "Meet Wolbachia: the male-killing, gender-bending, gonad-eating bacteria." *Science & Exploration* (2011): 1-4.
23. Triplehorn, C. and N. Johnson. *Borror and Delong's Introduction to the Study of Insects, 7th Edition*. Belmont: Brooks/ Cole, 2005.
24. U. S. Census Bureau. *Fact Finder Census Government*. 2014. http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src =bkmk. 26 April 2016.
25. Vavre, F., et al. "Infection polymorphism and cytoplasmic incompatibility in Hymenoptera-Wolbachia associations." *Heredity* 88 (2002): 361-365.
26. Werren, J. and D. Windsor. "Wolbachia infection frequencies in insects: evidence of a global equilibrium." *The Royal Society* 267 (2000): 1277-1285.
27. Werren, J. "Biology of Wolbachia." *Annual Review of Entomology* 42 (1997): 587-609.
28. Werren, J., W. Zhang and L. Rong Guo. "Evolution and Phylogeny of Wolbachia: Reproductive Parasites of Arthropods." *Royal Society Publishing* 261.1360 (1995): 55-63.