

SUPPORTING ELEMENTARY EDUCATION IN-SERVICE TEACHERS'
PROFICIENCY IN PLANNING STEM-CENTRIC LESSONS

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ABSTRACT

The purpose of this study was to explore the McDaniel College Elementary STEM Instructional Leader (ESIL) pilot cohort's ability to proficiently plan lessons that incorporated the *Maryland State STEM Standards of Practice (SOP)*, targeting integration of STEM content, inquiry learning, students' abilities to collaborate as a STEM team and students' strategic application of technology. Data collection, in the form of reviewing and analyzing study participants' lesson plans and self-reflections, was completed by three independent assessors. The researcher examined the interrater reliability among the three assessors using the Fleiss' kappa statistic. A 0.91 proportion of agreement consensus was documented among the three assessors. A test of hypothetical value was conducted using the nonparametric Wilcoxon-signed-rank Test. Interpretation of the Wilcoxon-signed-rank Test results suggest that the sample population demonstrated proficient planning abilities for the four targeted *Maryland State STEM SOP*.

Findings from this research add to the field's knowledge of elements in the promotion of graduate coursework that leads to elementary in-service teachers' proficiency in planning STEM-centric lessons, however the findings also have broader implications for teacher education at large. The McDaniel College ESIL model could frame K-12 teacher education for both pre-service and in-service teachers. The pragmatic, hybrid experience maximizes flexibility, promotes analytical thinking and self-reflection and builds communication skills. The introduction and development of inquiry and design-based learning through the 7E Learning

Cycle develops the teachers' understanding of practices promoted not only within the *Maryland State STEM SOP*, but also within the *Next Generation Science Standards*. The McDaniel College ESIL model also builds upon the collective efforts of academia, a non-profit STEM research facility, and local school divisions to align efforts that may lead to transformational changes for education. Essential ingredients for systemic change are embedded within the McDaniel ESIL model.

Keywords: Elementary Education, STEM Education, Instructional Leader, Lesson Planning, STEM-centric Lessons, Professional Development, Professional Learning Experiences, Inquiry, Teacher Cohort Model

Dedication

I dedicate this work to my mother, father, and daughter who are my roots and wings. My father instilled in me a curiosity and joy for learning that shaped my approach to life and teaching. My mother grounded me, teaching me how to attain goals, one step at a time. My daughter keeps me humble and real. Without their love and support, past and present, I would not have set my sights on this goal, nor be who I am today.

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CHAPTER 1: INTRODUCTION

1.1 Overview

Teacher quality is increasingly cited as one of the most critical factors impacting student learning (National Research Council, 2010). Bybee (1993) and the *National Science Education Standards* both point to teachers as the most important and decisive components in reforming science education (Bybee, 1993; NRC, 2010). Identifying and developing attributes of effective teachers is one way to improve teaching and, as a result, positively impact student learning (Drew, 2011). A few attributes held in common by effective teachers have been verified. There is consensus that effective teachers have a deep understanding not only of the content they teach, but pedagogy that translates content into learning experiences (Darling-Hammond & Youngs, 2002; Kukla-Acevedo, 2009). Effective teachers simplify learning into single ideas when needed and extend those ideas into multiple connections to help learners build and rebuild their own knowledge (Darling-Hammond & Youngs, 2002; Drew, 2011; Kukla-Acevedo, 2009; Stronge, Ward, Tucker & Hindman, 2008). Effective teachers ask higher level questions, use a variety of instructional strategies, and plan lessons that match methods and materials to student needs (Kukla-Acevedo, 2009; Stronge et al., 2008).

The decisions teachers make while planning lessons impact student learning and classroom behavior (Lardy, 2011; Palmer, 2006). A teacher's content knowledge, while important, is augmented by an understanding and ability to deliver that content using relevant content pedagogical strategies that meet students' needs (Darling-Hammond, 2000; Gunning, 2010). Teachers with more in-depth knowledge of science make deliberate choices in their lesson planning that support student-centered and inquiry-based instruction (Wing-mui So, 1997).

National reforms, such as the *Next Generation Science Standards (NGSS)*, have changed the content and pedagogy teachers must master (NRC, 2015). The *NGSS* outline performance expectations that push student learning toward deeper understanding of core ideas, demonstration of scientific and engineering practices, and the integration of crosscutting concepts (NRC, 2015). These standards take a more comprehensive look at integrating science content with engineering practices, defining a new vision for science instruction that incorporates knowledge and skills needed for the 21st century and elevating engineering design to the same status as scientific inquiry for teaching K-12 science (Achieve, Inc., 2013c; Lederman & Lederman, 2014; Pruitt, 2014; Robelen, 2010). This approach requires teachers to embrace inquiry- and design-based teaching practices (NRC, 2015).

Teachers have struggled for years to move toward inquiry instruction (NRC, 2000). Design-based teaching adds a new challenge to the mix, but the efforts are worth the time and energy (Cunningham & Carlsen, 2014). Effective integration of the engineering design with science has been proven to increase students' understanding of science concepts (Cunningham & Carlsen, 2014; Nargund-Joshi & Lui, 2013; Wendell & Rogers, 2013). Engineering design builds authentic context for science inquiry. Building teachers' understanding of the *NGSS* and preparing them to integrate engineering with science will require targeted professional learning experiences (Banilower, Gess-Newsome & Tippins, 2014; Lederman & Lederman, 2013).

Understanding and teaching the *NGSS* is a challenge for all who teach science, but an even greater mountain to climb for elementary science teachers. Elementary teachers are generalists and, for many, teaching science is out of their comfort zone (Trygstad, 2013). Lardy (2011) described how elementary teachers' lack of confidence with the content results in didactic teaching where science becomes little more than a vocabulary lesson and list of facts. Adding

the *NGSS*' new demands to integrate engineering design with science instruction will compound elementary teachers' reluctance to teach inquiry and student-centered science, and create a need for professional learning experiences tailored for elementary teachers (NRC, 2015).

1.2 Nature of the Problem

A lack of knowledge and skills to teach science, let alone integrate engineering design with that science, leaves elementary teachers ill-prepared to deliver the instruction called for by the *NGSS* (NRC, 2015). Professional development will be essential, but it must be professional development that is sensitive and attentive to elementary teachers' needs, addressing their narrow understanding and minimal experience with planning and teaching inquiry and design-based instruction (Capobianco & Rupp, 2014; NRC, 2015). A starting point is to match the current status of elementary teachers' knowledge and abilities to teach science and engineering with what is known about the design and implementation of effective professional learning experiences and needs of adult learners.

Elementary Teachers' Abilities to Plan and Teach Science

Elementary science instruction lacks an inquiry and student-centered approach and is characterized as facts delivered by teachers for student consumption (Lardy, 2011). One reason for this pedagogy is elementary teachers' lack of training in science content and science instruction (Lardy, 2011). *The Status of Elementary School Science* report, conducted within the *2012 National Survey of Science and Mathematics Education*, found that very few elementary teachers have an undergraduate or graduate degree in science or engineering and about one-third have five or less years of experience teaching science (Trygstad, 2013). Elementary teachers surveyed indicated that 90% had taken a college course in life science, followed by about 65%

completing coursework in Earth science, and less than half ever taking a course in either physics or chemistry.

When elementary teachers were asked to describe their feeling of preparedness to teach science, mathematics, reading and social studies in the *2012 National Survey*, science ranked as the area in which they felt least prepared (Trygstad, 2013). Within the sciences, teachers felt most comfortable teaching life science and Earth Science. Only 17% indicated they felt *well prepared* to teach physical science. Within this same survey, nearly twice as many teachers considered themselves well prepared to teach mathematics.

The *2012 National Survey* results found that elementary teachers have conflicting perspectives concerning planning, approach, and implementation of effective science instruction (Trygstad, 2013). The majority agree that learning science requires time for student discourse, and instruction should include a summary of key ideas, an identified purpose, and a connection of new learning to past learned concepts and skills. The majority also agreed with current science education reform that students should be given time for more in-depth study of fewer topics.

Many elementary teachers surveyed responded in ways that reflect traditional teacher-centered instruction (Trygstad, 2013). Forty-five percent of the teachers indicated that their first step in teaching science begins with explaining ideas to students *prior* to student exploration, and more than half indicated that hands-on and laboratory activities should be used to reinforce, not introduce, student learning. Eighty-five percent of the teachers surveyed begin science instruction by introducing new vocabulary.

This aligns with phenomena described in the National Research Council's report, *Taking Science to School* (NRC, 2007). For many elementary teachers, instruction in undergraduate

programs depicts science as a string of facts and science investigation a rigid set of steps under the umbrella known as the scientific method (NRC, 2007). Teaching as they were taught, elementary teachers model what they have learned, teaching content knowledge separate from science process skills instead of developing learning experiences that ask students to use science practices to build their own content knowledge (Nespor, 1987). Students should learn science by doing science, not by reading about science (Duschl, Shouse, & Schweingruber, 2007; Michaels, Shouse & Schweingruber, 2008). The *NGSS* calls for a reform and research-based, inquiry-approach to instruction, in contrast to didactic, teacher-directed learning (Banilower et al., 2014; Chai, Teo & Lee, 2009).

Elementary Teachers' Abilities to Plan and Teach Engineering

Prior to the advent of the *NGSS*, the National Academy of Engineering (NAE) and National Research Council (NRC) pushed for a coherent integration of engineering into K-12 education (Katehi, Pearson, & Feder, 2009). NAE and NRC claimed that integrating engineering into classrooms would improve “student learning and achievement in science and mathematics, increase technological literacy, and build students’ understanding of engineering content, the design practice, and career pathways” (Katehi et al., 2009, p. 49 - 50).

When elementary teachers were asked questions related to their preparation to teach engineering in the *2012 National Survey of Science and Mathematics Education*, virtually no one (0.4%) noted that they had completed any engineering courses and the vast majority identified engineering as a topic they were not adequately prepared to teach (Trygstad, 2013). Elementary teachers’ lack of experience with engineering has sometimes been expressed as misconceptions that reflect student misunderstandings, including notions that engineers are construction workers and train drivers who fix, build, and use engines and tools (Lachapelle, Hertel, San Antonio &

Cunningham, 2014). Elementary teachers see more benefits in teaching science than engineering (Lachapelle et al., 2014).

Understanding and developing learning experiences that effectively use the scientific and engineering practices in the *NGSS* will be difficult for elementary teachers, but well worth the struggle (NRC, 2015). Studies following teachers' implementation of *Engineering is Elementary* units, curricula that integrates engineering, science, and technology, indicated an increase in students' problem solving abilities, teamwork, and deeper thinking (Rynearson, Douglas, & Diefes-Dux, 2014). Preparing elementary teachers to teach science and engineering content and practices needs to be addressed through professional learning experiences.

Effective Professional Learning Experiences and Adult Learners

According to Rogers' Diffusion Theory in Education (2010), effective teacher professional learning builds upon stages of acquiring, using, and incorporating new knowledge into practice. Teachers want to collaborate with their colleagues and need a purpose for new learning, as well as an immediate opportunity to practice what has been learned in their own classrooms (Fisher, 2005; Rogers, 2010). Job-embedded learning experiences allow teachers to bring new innovations directly into their classrooms for practice, experimentation, and modifications (Zepeda, 2015). These opportunities build relevance, feedback, and transference of new experiences into a teacher's workplace, and can make or break the acceptance of new programs (Darling-Hammond, 1997; Fisher, 2005; Zepeda, 1999).

Learning Forward, formerly the National Staff Development Council, confirms this best practice (National Staff Development Council, 2001). For teachers to shift their instruction in ways that impact student learning, *Learning Forward* advocates for results-driven, job-embedded professional learning experiences. Professional learning needs to be flexible (Ernst, Segedin,

Clark, & DeLuca, 2014; Segedin, Ernst, & Clark, 2013). According to Posnanski (2002), most teachers prefer a setting where they may practice student-learning themselves, reflect on tasks with peers, and interact with a facilitator. Cunningham and Carlsen (2014) support this claim, suggesting that constructivist-based professional learning experiences give teachers the opportunity to reflect on their own learning theory, practice and content knowledge in reference to effective teaching and student learning.

Changes in teacher practice require time (Ernst, Clark, DeLuca, & Bottomley, 2013). Sustained, long-term training has been noted to have greater impact, with some suggesting as much as 80 hours or more required to transform teacher practice (National Science Board, 2008). Instilling changes in teacher practice has been cited as a barrier to wide adoption of an inquiry approach to science teaching (Garet, Porter, Desimone, Birman & Yoon, 2001; Posnanski, 2002).

Professional learning experiences that focus on content, incorporate active learning for the teacher participants, integrate directly into classrooms, and build a community of learners set the stage for transformational change (Garet et al., 2001; Schlang, 2006; Weiss & Pasley, 2006). Guskey (2002) confirms that teachers want pragmatic learning experiences that can be directly integrated into their classrooms and immediately benefit student learning. Strategies that impact student learning outcomes are adopted and then, adapted as needed (Guskey, 2002). As with all adult learners, teachers are most receptive to learning that impacts and has direct relevance to their work, interested in immediately applying what they learn to their classroom (Knowles, 1989; Pappas, 2013).

Educational reform and ever increasing demands for teacher accountability call for a greater understanding of teacher practices that positively impact student achievement (Richard, 2004). The 2014 *STEM Integration in K-12 Education* report from the NAE and the NRC

identified developing educators' abilities to plan and teach science and engineering as "key factors in determining whether integrated STEM education can be done in ways that produce positive outcomes for students" (Honey, Pearson & Schweingruber, 2014, p. 7). To provide effective STEM instruction, teachers will not only need to build students' proficiency within the individual STEM content areas, but help students develop the ability to see connections among disciplines (Honey et al., 2014).

States Supporting Educational Reform

States are taking action to support educational reform and investing in ways to develop teacher competence and quality through teacher selection, preparation and certification (Darling-Hammond, 2000; Epstein & Miller, 2011). Twenty-six lead states supported the *NGSS* development in its planning and early writing stages. These lead states committed to consider and develop implementation plans for the *NGSS* adoption. Currently, thirteen states and the District of Columbia have adopted the standards. The states include: Rhode Island, Kentucky, Kansas, Vermont, California, Delaware, Washington, Nevada, Oregon, Illinois, New Jersey, West Virginia, and Maryland (Achieve, Inc., 2015a).

In addition to adopting the *NGSS*, Maryland STEM initiatives have been driven by a Governor's Task Force on STEM Education that created a STEM office within the Maryland State Department of Education (MSDE) (Maryland State Department of Education, 2012). The MSDE STEM office has developed *STEM Standards of Practice (SOP)* and supporting resources to be disseminated by county STEM coordinators. Maryland's STEM initiatives are focused on enhancing elementary and early childhood teachers' preparation to teach STEM (MSDE, 2012).

The success of education reform is tied to the effectiveness and abilities of teachers (NRC, 2010). Maryland's adoption of the *NGSS* and commitment to STEM initiatives create a

need for transformational professional learning experiences for its elementary teachers. Using *Race from the Top* funds, MSDE encouraged Maryland colleges and universities to develop elementary Instructional Leader endorsement programs to prepare pre-service and in-service teachers to develop and implement STEM-centric learning experiences (MSDE, 2012).

Participating higher education institutions have developed teacher education programs that focus on building elementary teachers' STEM content knowledge, demonstrate their competence and confidence to deliver STEM instruction, and strengthen their abilities to develop STEM lessons and performance assessments (MSDE, 2013a). These programs are in their infancy. As the first wave of teachers complete this coursework, it is necessary to assess the impact of these programs.

1.3 Rationale for the Study

McDaniel College teamed with Carroll County Public Schools (CCPS) and the National Institute of Aerospace's Center for Integrative STEM Education (NIA-CISE) to design and pilot a series of elementary STEM graduate education courses that lead to the MSDE's Instructional Leader: STEM (PreK-6) endorsement for in-service teachers (Appendices A and B). This collaborative work resulted in professional learning experiences for elementary in-service teachers to increase their expertise in STEM content and pedagogy. An essential element of this coursework focuses on lesson design that incorporates science and engineering practices through inquiry- and design-based learning (McDaniel, 2015a).

The criteria for the MSDE Instructional Leader endorsement requires educators, with an early childhood or elementary education certificate, to complete a minimum of 18 semester hours addressing STEM content and practices (MSDE, 2013a). Specific courses were not dictated, but state regulations identified content areas to be included within coursework, including "authentic

problem-based and project-based learning; skills including questioning, spatial reasoning, communication, critical thinking, and problem solving; engineering design process; application of scientific practices and content; application of mathematical practices and content; technology literacy; and collaborative learning” (MSDE, 2013a). MSDE regulations also require three semester hours of coursework to address “leadership knowledge and skills” and an additional three semester hours for a school-based internship or practicum (MSDE, 2013a). This coursework prepares educators to develop lessons that incorporate engineering design processes, scientific and mathematical practices and content, and real-world problem-based and project-based learning. Coursework leading to this endorsement emphasizes teaching through questioning and developing lessons that build critical thinking, problem solving, and communication and collaborative skills.

Working with NIA-CISE, Graduate and Professional Studies (GPS) at McDaniel College developed the Elementary STEM Instructional Leader (ESIL) graduate program, a series of six courses, aligned with MSDE’s requirements for the Instructional Leader: STEM (Pre-K) endorsement. The coursework was developed following elements of the 1995 Haney and Lumpe Teacher Professional Development Framework, a research-based model guided by reform policies and teachers’ needs. Haney and Lumpe’s work is a conceptual change model that empowers teachers to accept decision-making opportunities that lead to changes in teacher practices and more positive perceptions toward science education reform (Haney & Lumpe, 1995). Three interdependent stages -- Planning, Training, and Follow-up -- frame this model (Haney & Lumpe, 1995; Posnanski, 2002).

1.4 Purpose of the Study

The NAE and NRC research agenda, outlined within *STEM Integration in K-12 Education*, recommends providing professional learning experiences for teachers to prepare them to deliver integrated STEM instruction (Honey et al., 2014). Maryland, one of the early adopters of the *NGSS*, recognized the need to provide targeted and coherent professional learning experiences for its elementary teachers to transform their STEM planning and teaching practice. MSDE addressed this need by developing the Instructional Leader: STEM (PreK-6) endorsement and turning to higher education institutions to provide learning experiences for elementary teachers that would lead to this endorsement (MSDE, 2014a). In response to MSDE's call, McDaniel College designed the ESIL graduate series. The coursework, developed following a best-practice model for professional learning, was designed to prepare elementary in-service teachers to integrate STEM content and the *Maryland State STEM SOP* into their planning and teaching.

This study used a state-approved key assessment task to explore the McDaniel College ESIL pilot cohort's ability to *proficiently* plan lessons that incorporate the *Maryland State STEM SOP* targeting integration of STEM content, inquiry learning, students' abilities to collaborate and students' strategic application of technology.

1.5 Research Questions

This study explored the proficiency of STEM lesson design by the group of elementary teachers who first piloted and completed McDaniel College's ESIL program. MSDE expects STEM lessons to “answer complex questions, investigate global issues, or develop solutions for challenges and real world problems” (MSDE, 2012). In addition to this baseline expectation, the

Maryland State STEM SOP target additional criteria that are identified within this study's research questions.

The research questions guiding this study are:

RQ#1: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that ***integrate science, technology, engineering, and mathematics disciplines?***

RQ#2: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that ***engage students in inquiry?***

RQ#3: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that ***support student collaboration as a STEM team?***

RQ#4: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that ***support students' strategic application of technology?***

1.6 Design of the Study

Upon completion of the five courses within the McDaniel College STEM Education series, teachers demonstrated their changes in practice through a practicum and the creation of a digital portfolio. Six key assessments were included in the digital portfolio. Each assessment targeted an aspect of the teachers' STEM content knowledge and pedagogy, focusing on the teachers' abilities to plan instruction and assess student learning.

This study used a quantitative approach to analyze *Key Assessment 3* within each pilot teacher's digital portfolio. *Key Assessment 3* targeted the teachers' abilities to design STEM-centric lessons that focus on four of the seven *Maryland State STEM SOP*. *SOP2* focuses on the students' abilities to integrate content within the four STEM disciplines. *SOP4* expects students to seek knowledge through an inquiry approach to learning. *SOP6* guides students to work collaboratively and *SOP7* emphasizes understanding and applying technology strategically.

The *Maryland State STEM SOP* frame students' STEM literacy, describing students' behaviors, attributes and abilities, while challenging students to use their knowledge to develop solutions for real world problems (MSDE, 2013b). Appendix C lists all seven *Maryland State STEM SOP*.

The test of hypothetical value was used to support whether or not the teachers' demonstrated *proficiency* in STEM-centric lesson design. Three independent assessors used the MSDE-approved rubric to assess the pilot teacher's lesson plans and analytic reflections to measure the cohort's proficiencies in planning STEM lessons. Consensus estimates among the raters at a value of 0.90 or greater, using the Fleiss' kappa statistic, was the measure identified to confirm the assessors' reliability.

1.7 Limitations and Assumptions

There are several limitations inherent in the design of this study. *Key Assessment 3* includes only one lesson plan analyzed by the pilot participants. A review of more than one plan might render different outcomes. Five of the six McDaniel College graduate courses have been developed and facilitated by one course developer who has also been the instructor. The instructor for these courses is the researcher for this study. The pilot group for this study is from one school district. Second, third and fourth cohorts from this same district are currently working through the graduate series to increase capacity.

Once the pilot is completed, there are plans to offer the series to neighboring counties in Maryland. Newport News City Public Schools, in Virginia, has contracted with McDaniel College for a small group of teachers to complete five of the six courses. Teaching the courses to educators in other counties and states will test the applicability of the coursework to prepare extended teacher audiences to develop STEM-centric lesson plans.

It is an assumption that a teacher's ability to plan STEM lessons will result in that teacher's ability to implement these lessons. This study focused on the pilot cohort's proficiency in the niche of lesson design. Another group of teachers may not respond to the coursework with similar results, limiting possibilities for this coursework to broaden participation.

1.8 Definitions of Terms

Some terms were used during this study with explicit meanings for the researcher and cohort teachers. For clarity, these terms are defined.

Andragogy. Andragogy refers to strategies and best practices to design learning experiences for adult learners. It focuses on facilitating adult learning and helping adults apply knowledge to real life settings (Forrest & Peterson, 2006; Knowles, 1977; Terehoff, 2002). The work of Malcolm Knowles is often referenced in discussions about andragogy, in particular Knowles Assumptions that frame the needs of adult learners (Atherton, 2011; Batson, 2008; Knowles, 1977).

Cohort. Elementary teachers were identified by principals and curriculum specialists, and then invited to join the cohort to pilot the McDaniel College graduate series. Graduate coursework is paced for the cohort so that teachers complete a 3-credit class in the fall, spring, and summer semesters, aligned with the county's graduate course reimbursements. The county and college arrange payments to alleviate any costs for teacher participants.

Community of practice. A community of practice is a group of professionals who “share knowledge, promote learning, and build expertise in a particular area” (Zepeda, 2015, p. 154).

Constructivist learning. Constructivist learning builds a setting where students create their own understandings based on what they already know and believe (Richardson, 2003). Learning is student-centered and teachers facilitate active learning experiences where students often work in collaborative groups (Sublette, 2013).

Design-based learning (DBL). Within design-based learning, students build their understanding of content and practices framed by the context of designing a solution for a challenge or to meet a need (Wells, 2010). DBL promotes learning guided by students using the

design process while working in collaborative teams. This focus builds relevance for student learning (Gardner, 2012; Wells, 2010).

Inquiry learning. Inquiry learning includes student activities that develop the habits, knowledge, and understanding of science in parallel to thinking and acting like scientists (NRC, 2000). These include opportunities for students to ask questions, seek knowledge through research activities, plan investigations, use tools to gather evidence, analyze and interpret data, and share results.

Job-embedded. Job-embedded professional learning experiences are conducted with the teachers' students, the school system's curriculum, and within the school venue (Zepeda, 2015). This work is characterized by relevance, feedback from a variety of supporters, and immediate transference of newly learned skills into the work place (Dana, 2010; Zepeda, 1999). The pilot cohort developed their lessons using the school district's curriculum and implemented these lessons within their classrooms. All work was immediately transferred into action.

Key Assessments Tasks. The MSDE program approval and national accreditation, through the National Council for Accreditation of Teacher Education (NCATE), requires colleges and universities to incorporate a performance assessment system into each accredited program (MSDE, 2003). Four key assessments are required for completion of the McDaniel College ESIL program. An additional two key assessments, for a total of six, are required for teachers to earn the MSDE Instructional Leader: STEM (PreK-6) endorsement. Each key assessment includes a task and associated analytic rubric to assess the task. A matrix of the key assessments is included in Chapter 2. McDaniel College graduate programming currently holds legacy NCATE accreditation, but is transitioning to the governance of the Council for the

Accreditation of Educator Preparation (CAEP) as the new accrediting body for educator preparation (NCATE, 2015).

Maryland State STEM Standards of Practice (SOP). The *STEM SOP* guide STEM instruction by defining the combination of behaviors, integrated with STEM content, which are expected of a proficient STEM student. These behaviors include engagement in inquiry, logical reasoning, collaboration, and investigation. The goal of STEM education is to “prepare students for post-secondary study and the 21st century workforce” (MSDE, 2013b).

Proficient. All teachers within this study completed *Key Assessment 3* that assessed whether they were proficient in planning lessons that integrate science, technology, engineering and mathematics; engage students; support students working collaboratively as STEM teams; and support students strategically applying technology. The rubric for *Key Assessment 3* defines proficient as earning 27 – 39 points out of a possible 52 points on an analytic rubric (McDaniel, 2015b). Thirteen separate indicators within the analytic rubric are each assessed on a scale of 1 (unsatisfactory) to 4 (exemplary). Proficient is a 3 on this scale. *Key Assessment 3* can be found in Appendix D.

STEM-centric. MSDE defines STEM-centric as “the development or modification of units, lessons, or activities to incorporate the *STEM SOP* and reflect the definition of STEM Education” (MSDE, 2014).

STEM Education in Maryland. MSDE defines STEM Education as “an approach to teaching and learning that integrates the content and skills of science, technology, engineering, and mathematics” (MSDE, 2014b).

1.7 Summary

This dissertation is organized into five chapters. Chapter 1 outlines how and why this study adds to the field's knowledge of effective graduate education coursework that results in teachers' proficiency in planning STEM-centric lessons. The Overview, Nature of the Problem, Rationale for the Study, and Purpose of the Study sections frame the importance and significance of this study. This chapter also clarifies the study's intent through the Research Questions, Design of the Study, Limitations and Assumptions, and Definitions of Terms sections.

Chapter 2 presents a synopsis of relevant literature related to elementary curricula design suited for inquiry- and design-based learning, adult learning models, and professional development. This literature review builds foundational knowledge to study professional development tailored to meet the needs of elementary teachers learning how to design and plan STEM-centric lessons. Chapter 3 describes the methodology used to study the research questions, including pertinent information about the study group, the instruments used in the study, and the data collection and data analysis. Chapter 4 outlines the data collected during the study, and chapter 5 synthesizes the conclusions drawn from the collected data. Chapter 5 also outlines limitations of the results, implications of the study, and possible future considerations for this researcher and other researchers.

The research study presented in this dissertation will add to the field's knowledge of elements in the promotion of graduate education coursework that leads to elementary in-service teachers' proficiency in planning STEM-centric lessons.

CHAPTER 2: LITERATURE REVIEW

2.1 Theoretical Framework

With the advent of the *NGSS* and state-based STEM initiatives, elementary teachers are being asked to design and plan lessons that embed scientific and engineering practices and STEM-centric learning into instruction (NRC, 2015; MSDE, 2014b). This study explores the challenges in preparing elementary teachers for this task and is rooted in theories of curricula planning models for elementary education, successful models of professional development, and adult learning theory. A review of related *NGSS*, the *Standards for Technological Literacy (STL)* and *Maryland's State STEM SOP* is included to frame the context for the participants within this study. This chapter also describes the theoretical and practical framework for the McDaniel College ESIL program as it embodies elements of elementary curricula, professional development and adult learning theory previously reviewed.

2.2 Pertinent National and State Standards

National Standards

The *NGSS* describe proficiency in science for all students (Achieve, Inc., 2013c). Three dimensions of learning are defined within these standards: Practices, Crosscutting Concepts, and Disciplinary Core Ideas (DCI). DCI focus K-12 science curriculum, instruction, and assessments on important aspects of science, while Crosscutting Concepts link science domains through broad-based themes. The Science and Engineering Practices (SEP), listed in Table 1, describe the behaviors inherent in scientific inquiry and engineering design, defining engineering design as a systematic practice for solving problems (Achieve, Inc., 2013c; NRC, 2015). The inclusion of the engineering practices within the *NGSS* raises engineering design to the same level of

importance as scientific inquiry and provides opportunities for the practices to work in tandem for an integrated approach (Achieve, Inc., 2013c; Capobianco & Rupp, 2014; NRC, 2015).

Table 1

NGSS Science and Engineering Practices (SEP)

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

The *NGSS* define a new vision for student proficiency which must be supported by a new vision for science instruction. (Achieve, Inc., 2013c). Teachers will need to design and plan student-centered lessons that support inquiry- and design-based instruction (NRC, 2015). The *NGSS* have been adopted by thirteen states and the District of Columbia (Achieve, Inc., 2015a). Maryland is one of the early adopters of the *NGSS* and the state as a whole, and each county within the state, are currently redesigning science curriculum to align with these national standards.

The *STL*, national standards for technology education, promote the need for technological literacy for all students and advocate for the study of technology as a core field within K-12 education (ITEA, 2000). Twenty standards and supporting benchmarks create a blueprint for educators. Within those twenty standards, standards 8, 9, 10, and 11 focus on what students should know and be able to do under the umbrella of engineering and design-based practices. These four *STL* are listed in Appendix E. *STL* 8, 9, 10, and 11 and the *NGSS* are national blueprints defining what science, technology, and engineering content and practices should be taught and suggesting ways to integrate these disciplines.

State Standards

In 2011, the MSDE set a vision for STEM Education within Maryland. As part of this vision, STEM Education in Maryland was defined as:

“an approach to teaching and learning that integrates the content and skills of science, technology, engineering, and mathematics. *STEM Standards of Practice* guide STEM instruction by defining the combination of behaviors, integrated with STEM content, which are expected of a proficient STEM student. These behaviors include engagement in inquiry, logical reasoning, collaboration, and investigation. The goal of STEM education is to prepare students for post-secondary study and the 21st century workforce” (MSDE, 2013b).

The *Maryland State STEM SOP* were developed as process standards to guide instruction and describe “the behaviors of a STEM proficient student” (MSDE, 2013b). Maryland educators use the *SOP* to guide the design and planning of STEM-centric units and lessons focusing on “answering complex questions, investigating global issues, and developing solutions for challenges and real world problems” (MSDE, 2012). The *SOP* are listed in Appendix C.

The *NGSS*, *STL*, and *Maryland State STEM SOP* are coherent and systemic roadmaps that define what should be taught (Achieve, Inc., 2015b; MSDE, 2013b). These reform documents outline changes in classroom practice that rely on teachers for their success and set reference points for the selection of curricular models that best support the design of lessons that incorporate scientific and engineering practices and STEM-centric learning (Borko, 2004; Garet et al., 2001; Darling-Hammond et al., 2009). Reform documents are the backbone of effective professional development and integral components of school improvement plans (Koba & Wojnowski, 2013; Zepeda, 2012).

2.3 Curricula Planning Models for Elementary Education

Current learning science is rooted in constructivist theory, describing students as actively constructing or building their knowledge based on what they already know to make sense of

learning (Richardson, 2003; Uden & Beaumont, 2006). Meaning is created and initiated by problems, questions, and real world tasks; and problems and collaboration are central to constructivist learning (Dittmer, 2013). Learning is student-centered and teachers facilitate students working in collaborative groups using active learning (Sublette, 2013). Constructivism, as a curriculum model, promotes higher-order critical thinking (Ormond, 2014).

Brain research supports the constructivist view that learning is an active process and that the brain is motivated by searching for meaning and seeking patterns (Young, 2005). Learning is provoked by challenges and inhibited by threat. The NRC's 1999 study of *How People Learn* suggests that students must actively engage with their prior understanding and explanations to either reinforce correct impressions or de-construct and reconfigure misconceptions (Bransford, Brown, & Cocking, 1999). Based upon this study, students need to take an active role in defining their learning goals and organizing their learning within a conceptual framework for easy storage and retrieval (Bransford, et al., 1999).

Brain research and constructivist learning are the springboards for reviewing K-12 lesson and curriculum models that provide frameworks to support STEM-centric lessons incorporating scientific and engineering practices.

K-12 Lesson Curricular Models

Several curricular models globally interface into K-12 education, framing and supporting the tenants of constructivist learning: Problem-based Learning (PBL), Project-based Learning (PjBL), Integration, and Inquiry and Instructional Cycles.

Problem-based Learning and Project-based Learning. PBL uses ill-structured, real-world problems as vehicles and the context to frame student learning (Gallagher, Stepien, Sher, & Workman, 1995). Teachers design PBL tasks as focused, experiential learning, reflecting

Dewey's beliefs that students learn best by doing and thinking through problems (Barth, 2013; Gallagher et al., 1995; Ormand, 2014; Uden & Beaumont, 2006). Well-constructed problems are realistically complex and require student teams to collaboratively seek and apply what is learned to solve the problem. Teachers direct learning by assuming the role of a facilitator (Barth, 2013; Uden & Beaumont, 2006). PBL pedagogy builds *need to know* specific content and process skills (Dittmer, 2013; Gallagher et al., 1995). Knowledge acquisition and application is integrated, simulating the work of practitioners. PBL learning has been cited to increase student motivation and retention of content knowledge and provides an immersive setting where students may develop attitudes and habits of mind of practitioners, emulating authentic behavior within a real-world context.

Although there is not currently a robust research base, two noted PBL programs support design-based and integrated STEM instruction. *Design-based Science* integrates science and engineering for 9th graders (Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005). This coursework was studied to better understand how PBL instruction guides students to apply new science knowledge and problem solving skills to a real-world problem. Preliminary findings support an increase in students' abilities to transfer knowledge and an increase in student interest in STEM fields (Fortus et al., 2005). *Learning by Design*, a second PBL program, uses ill-structured problems to integrate physical and Earth science instruction with engineering and mathematics instruction (Brophy, Klein, & Rogers, 2008; Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, & Ryan, 2003). Students build and design devices that reflect their content knowledge of forces, motion, and Earth processes. Students within this program demonstrated increased comfort in questioning.

PjBL organizes learning through the completion of projects. Within both PBL and PjBL, students construct their knowledge through dynamic, interdisciplinary trial-and-error learning (Karacalli & Korur, 2014). Often real-world problems are central to PjBL. Research supports that students' knowledge retention is increased by PjBL generated experiments, reports, and presentations (Karacalli & Korur, 2014). A Vanderbilt study cited lower math anxiety and more positive attitudes toward math for a group of elementary students who learned math through PjBL (Sawyer, 2013). Both PBL and PjBL are student-centered models building on students' curiosity and empowering them to work collaboratively to question and apply knowledge and practices (Karacalli & Korur, 2014). Both build context for learning and help students make connections among disciplines.

Integration. Constructivism as a learning theory, and PBL and PjBL as curricular models, emphasize making connections, or integration, across disciplines (Karacalli & Korur, 2014). In its simplest form, integration is making connections and helping students see the big picture that frames learning (Barth, 2013; Bosse, Lee, Swinson, & Faulconer, 2010). Integration helps students see relevance to learning and recognize ways disciplines work together outside classroom settings. Drake and Burns (2004) place integration on a continuum and consider the process as a “matter of degree and method” (p. 8). Their work describes integration as multidisciplinary, interdisciplinary, or transdisciplinary. Multidisciplinary integration, on the lighter end of the integration spectrum, focuses on organizing disciplinary standards around a theme (Drake & Burns, 2004). Within interdisciplinary integration, the disciplines are identifiable, but less distinct. Curricular design is organized around common, cross-cutting concepts that unite core ideas and bridge disciplinary boundaries (Achieve, Inc., 2013b). Student questions and concerns drive transdisciplinary integration. “Students develop life skills as they

apply interdisciplinary and disciplinary skills in a real-life context” (Drake & Burns, 2004, p. 13). PBL and PjBL learning experiences often use a transdisciplinary approach.

Drake and Burns’ (2004) integration model wraps around what they call the KNOW/DO/BE framework. They suggest that curricular design should begin by asking these three questions:

- What is most important for students to KNOW?
- What is most important for students to be able to DO?
- What kind of person do we want students to BE?

The KNOW/DO/BE model organizes cross-curricular, broad-based content, skills, attitudes, and beliefs (Drake & Burns, 2004).

Inquiry and Instructional Learning Cycles. John Dewey and William James, as cited in Phillips (1995), were proponents of active constructivism and challenged what they called the “spectator theory of knowledge,” supporting a belief that learning requires active participation and doing. Unlike spectators at an athletic event, Dewey and James suggest that learning calls for students to participate in the game, not merely watch from a distance. Dewey also emphasized the importance of social interactions to build understanding and support learning. These beliefs frame the tenants of inquiry learning that places students in the role of thinking and acting like scientists (NRC, 2000). While inquiry learning has been a foundational pedagogical practice within current science reform since the 2000 release of the *National Science Education Standards*, it continues to be underused and misunderstood (Olson & Loucks-Horsley, 2000). Teachers have complained that inquiry is difficult to manage, takes too much time, and does not teach students what they need to know within a standards-based classroom. Many are confused as to whether inquiry is what students do or an approach to teaching (Goldston, Dantzler, Day, & Webb, 2013). Atkin and Karplus, working with the Science Curriculum Improvement Study

(SCIS), were some of the first to break inquiry into a three-phase learning cycle: Exploration, Term Introduction, and Concept Application (Bybee, Taylor, Gardner, Scotter, Powell, Westbrook, & Landes, 2006). This learning cycle is student-centered and driven by student questions. Students learn through doing and rich social interactions (Bybee, et al., 2006; Campbell, 2000; Goldston et al., 2013).

Bybee, working with the Biological Sciences Curriculum Study (BSCS), expanded the three-step learning cycle into the 5E Instructional Learning Cycle Model (Bybee, 1997; Bybee et al., 2006). Each step, or phase, of the 5E cycle begins with the letter E: Engage, Explore, Explain, Elaborate, and Evaluate. The 5E model helps teachers break an inquiry experience into more manageable components without sacrificing student-centered learning (Goldston et al., 2013). The Engage stage hooks students, encourages them to ask questions, and elicits prior understandings to check for possible misconceptions. Within this stage, students hinge new content and experiences on past learning. The Explore stage pushes students to find out more about the topic through lab activities, experiments, observations, or research. During the Explain stage students share their Explore findings with their teacher and classmates to align their explorations with conventional learning. At the Explain stage, the teacher helps students match their experiences with the actual concepts, processes, and skills focal to the study. Vocabulary may be introduced at this stage, allowing students to name that which has already been explored. The Elaborate stage of a 5E cycle challenges students to extend and apply their new learning to other topics and situations. The final stage, Evaluate, is actually an essential component woven throughout the learning cycle as both formative and summative assessment (Campbell, 2000; Goldston et al., 2013).

The 5E Learning Cycle, often referred to as simply the 5E Model, does not prescribe particular teaching strategies. Bybee (1997) and Bybee et al. (2006) suggest that the model frames learning experiences that support conceptual change and is most effective when guided by strategic questions. Questioning, both student- and teacher-driven, is essential to each of the 5E stages. Students need social interaction and collaborative learning to share ideas, argue, and question their peers (Campbell, 2000; Goldston et al., 2013)

The 5E Model has a growing research-base and can be intertwined with integration, PBL, and PjBL (Bybee et al., 2006). Researchers suggest that the use of this model increases students' understanding of content knowledge and reasoning skills more than traditional learning approaches, such as lectures followed by verification tasks. A relationship has also been found between the use of the 5E Model and more positive attitudes and interests in science (Bybee et al., 2006). The 5E Model has been used not only for lesson and curriculum design, but also within state and local science frameworks. It has also been used not only in formal educational settings, but in informal education and non-science disciplines.

Eisenkraft (2003) suggested expansion of the 5E model to a 7E model to bring deliberate attention to Eliciting prior knowledge and Extending the transfer of learning to real world settings. This model expands Engage to include both Engage and Elicit, noting the importance of Eliciting students' prior knowledge so that teachers may have a clear understanding of where learning should begin and possible student misconceptions. Elaborate expands to Elaborate and Extend to assure that knowledge is applied to a second context beyond the original Elaboration (Eisenkraft, 2003).

Underpinnings for STEM-centric Lesson Design

The strongest supporting frameworks underpinning STEM-centric lesson design are PBL, PjBL, Integration, and the Inquiry-based Instructional Learning Cycles. PBL and PjBL, by definition, propel learning through real world, integrated, contextual problem solving (Barth, 2013; Uden & Beaumont, 2006). Transdisciplinary integration is driven by students' questions and concerns within a real-life context (Drake & Burns, 2004). The 5E and 7E Learning Cycles move students through inquiry-learning using logical step-by-step stages. While originally designed as models for science instruction, the 5E and Models support student-centered, collaborative, creative, and critical thinking defined by both the *STL* and the *NGSS* (Bybee, 1997; Bybee et al., 2006; Eisenkraft, 2003).

Advocates of the *NGSS* are interested in aligning the 5E Model with the Engineering Design Process (EDP) (Asunda & Hill, 2007). EDP is, loosely, a series of steps engineers follow to solve a problem. These steps typically include: Plan, Build, Test, Improve, and Retest (Asunda & Hill, 2007). Some suggest that the 5E Explore phase is a logical spot for EDP experiences. Within the Explore students work to gather information that could answer a science question or design problem. There are varying ways teachers might guide students between the 5E and EDP to integrate science and engineering content and practices (Barth, 2013). Integrating science and engineering builds context and purpose for science instruction utilizing innovative practices within engineering. The design context frames learning that is reflective and adaptive. Young learners have the ability to describe, plan, and demonstrate their design thinking (Brophy et al., 2008).

Several of these curricula models are incorporated into the lessons designed by teachers participating in the McDaniel College ESIL program (McDaniel, 2015a). This approach builds

elementary teachers' abilities to design 7E problem-based lessons that use an engineering design challenge to drive student-centered learning. The McDaniel College ESIL model challenges teachers to develop integrated STEM lessons that incorporate both inquiry and design-based learning. Inquiry, problem-based learning, and the 7E instructional framework are umbrella strategies employed within the McDaniel College ESIL model, utilized to demonstrate content and practice integration while placing teachers in the role of active learners.

Challenges for Elementary Educators

Before elementary educators embrace integrating STEM-centric content and practices into their already packed day, a number of barriers need to be hurdled. A lack of knowledge and skills to teach science, let alone integrate engineering design with that science, leaves elementary teachers ill-prepared for the task of developing STEM-centric lessons (Capobianco & Rupp, 2014). Professional development is called for, but it must be professional development that is tailored to elementary teachers' limited understanding and minimal experience with planning and teaching inquiry- and design-based instruction.

Time. Teaching following PBL, PjBL, or Learning Cycles models requires greater upfront planning and, often, greater time for implementation. Time is in short supply for elementary educators (Campbell, 2000). Testing often drives decisions about how much time is dedicated to content and practices. Currently, teaching math, reading and writing trumps teaching science in elementary classrooms (Campbell, 2000; Nadelson, Callahan, Pyke, Hay, Dance, & Pfiester, 2013). In US schools, science instruction, on average, is only 10% of the total instructional time (Weiss, 1993). Data reported for the *2009 National Assessment of Educational Progress (NAEP)* indicated that 4th grade teachers, across the country, spent only 1.9 hours to 3.8 hours per week in science instruction (NRC, 2015).

One logical way to include more science in elementary classrooms is through integrating these areas with language arts and/or math (Campbell, 2000; Tice, 1999). Science process skills mesh well with reading and writing skills and, when integrated, offer students dynamic learning opportunities (Tice, 1999). Content and practices between science and math logically reinforce each other and build strong connections (Campbell, 2000). Integration has many sound educational benefits, already described at an earlier juncture, however the challenges of planning for integration requires increased planning time, often turning teachers away from this approach (Campbell, 2000).

Preparation to Teach STEM-centric Lessons. Many elementary teachers have an inconsistent and sometimes narrow understanding of science content, as well as a limited awareness of science pedagogical content knowledge (Morrison, 2013; Nadelson et al., 2013). Data collected within the *Status of Elementary School Science* report, part of the *2012 National Survey of Science and Mathematics Education*, indicated that very few elementary teachers have an undergraduate or graduate degree in science or engineering and about one-third have five or less years of experience teaching science (Trygstad, 2013). Typically, elementary educators complete two college-level science and math courses in preparation for their elementary certification (Nadelson et al., 2013; NRC, 2010). MSDE requires that elementary education majors complete twelve hours of both math and science to earn a Maryland elementary education certificate (MSDE, 2015). At a minimum, elementary educators need a foundational understanding of science to not only present the content accurately, but also to identify and address student misconceptions (Nadelson et al., 2013). Professional development focused on building an understanding of how to organize instruction around scientific ideas will help

prepare elementary teachers to create effective learning experiences for their students (NRC, 2010).

The *NGSS* expect educators to plan and implement instruction that is driven by student questions about scientific phenomena and/or engineering design problems (Achieve, Inc., 2013d; NRC, 2015). To do this, educators need to adopt an inquiry and design-based approach to teaching (Achieve, Inc., 2013a; NRC, 2015). Many elementary educators adhere to the textbook for science instruction. In a recent study, 90% of surveyed elementary educators equated science instruction with completing more than 75% of the assigned science textbook (Weiss, 1993). This tie to the textbook, by some, may indicate that elementary teachers feel unqualified to teach science.

To move elementary teachers from a textbook-coverage model to inquiry instruction will require more opportunities for elementary educators to experience inquiry (Nadelson et al., 2013; Tice, 1999). Within a recent study, attributes of six elementary teachers, identified as teachers with exemplary skills in implementing inquiry science, were analyzed (Morrison, 2013). These teachers held some shared experiences and perceptions. All described childhood experiences that nurtured their curiosity. The group agreed that inquiry instruction required teachers who were comfortable mentoring, guiding, and facilitating instruction. The teachers planned and implemented lessons where students were engaged in asking questions and offered time for student exploration. This group incorporated more formative than summative assessment in their planning and students did not fear failure. Based upon findings from this study, elementary teachers need their own inquiry learning experiences so that, through their own constructivist learning, they may create a framework to grow their knowledge of science content and pedagogy (Morrison, 2013). Science-specific professional development that leads to teacher adoption of

inquiry-based instructional practices requires time, as much as 40 – 79 hours (Cotabish, Dailey, Robinson, & Hughes, 2013).

In addition to addressing components of inquiry found within the science and engineering practices, educators must also adequately incorporate essential disciplinary core ideas and cross-cutting concepts into science instruction (Achieve, Inc., 2103c). This approach requires educators to have a systematic and integrative understanding of STEM content (Morrison, 2013).

The *2012 National Survey of Science and Mathematics Education* also gathered data that indicated that most elementary teachers are ill-prepared to teach engineering with few having any coursework in engineering and only 10% identifying themselves as fairly well or very well prepared to teach engineering (Trygstad, 2013). Using the Design, Engineering, and Technology (DET) teacher instrument, Hsu, Purzer, and Cardella (2011) found that elementary teachers, as a whole, agreed that teaching DET is important, though they do not feel prepared for the task. This survey used the phrase design, engineering, and technology to broaden the meaning of engineering and technology (Yasar, Baker, Robinson-Kurpius, Krause, & Roberts, 2006).

Results from the DET survey showed that elementary teachers with different teaching experiences have significant differences concerning stereotypical views of engineers (Hsu et al., 2011). Teachers with 6 – 15 years of experience, labeled as a moderate level of experience, were least familiar with characteristics of engineers and likely to have bias against girls' abilities to learn DET. Expert teachers, defined as teachers with more than sixteen years' experience, identified a lack of administrative support as a barrier for integrating DET into their teaching.

Female teachers were found to define technology as artifacts in comparison to male teachers' definition of technology as the application of science (Hsu et al., 2011). While the

group rated the importance of DET highly, minority teachers rated the importance of teaching DET significantly higher than the majority teachers.

Elementary teachers within the survey agreed that project planning and the use of engineering to develop new technologies were important components to teaching science (Hsu et al., 2011). These teachers indicated that they were motivated to teach science to encourage their students' enjoyment for learning, develop their understanding of the natural and technical worlds, and prepare them for careers in science, engineering, and technology.

Barriers to teaching DET included lack of time, training, and knowledge (Hsu et al., 2011). The group was interested in professional development opportunities that would not only increase their familiarity with DET, but address misconceptions related to engineers and engineering. The researchers suggested that planning and problem solving should be stressed within professional development, over building and testing within DET, and that professional development experiences should model the relationship among engineering, science, mathematics, technology and students' everyday life, helping to frame student learning in science and mathematics while supporting the development of problem solving.

Elementary teachers who do attempt to integrate engineering into their science instruction often focus only on the design process and many short change the final steps within that cycle (Capobianco & Rupp, 2014). Within a recent study it was observed that elementary STEM teachers implementing engineering design-based instruction spent most instructional time on the early phases of design: problem identification, brainstorming, and planning. Less time was allotted for students to actually build, test, share their ideas, and redesign. These results may link back to Hsu et al.'s findings that a lack of time, training, and knowledge are barriers to teaching DET (2011).

Another study reviewing elementary level design-based lessons noted that the lessons stressed qualitative thinking and little quantitative reasoning (Parsons, O'Hare, Little, Van Driessche, & Parsons, 2007). This lack of focus on data and math within the lesson may point to the teachers' lack of understanding of engineering and math's important role within engineering design.

Importance of Planning STEM-centric Lessons for Elementary Students

Teaching science, technology, engineering and math through an integrative lens as STEM can harness and expand the curiosity and enthusiasm inherent within elementary students (Nadelson et al., 2013). Introducing young learners to interesting STEM careers and a more realistic impression of STEM tasks could do much to encourage students to consider STEM professions (Boots, 2013; Nadelson et al., 2013). An 18% drop in high school students' interest in engineering careers between 1991 and 2007 was observed within one study (Jamieson, 2007). This same study cited that the majority of students entering undergraduate engineering programs are Asian males, followed by white and Chicano males, with a definite minority of white and Chicano females. Introducing engineering to elementary students and integrating engineering practices into science instruction, as early as grade one, builds student interest and participation in the study of engineering and science (Billings, 2011; Capobianco, Yu, & French, 2015). Engaging elementary students in standards-based engineering learning experiences improves "students' understanding of the work of an engineer, their own abilities to problem solve using math and science, and their aspirations in becoming engineers" (Capobianco et al., 2015, p. 289).

Misconceptions about the role of engineering have been identified within groups of elementary students (Capobianco, Diefes-Dux, Mena, & Weller, 2011; Cunningham, Lachapelle, & Lindgren-Streicher, 2005). More than 6000 elementary students surveyed about the work of

engineers found a majority of students thinking engineers are car mechanics and construction workers. This group of students associated engineering with construction, building, machinery, and vehicles and when asked what they thought engineers did, most commonly answered “fix things” (Cunningham et al., 2005). A similar study asked students to draw a picture of an engineer. Most students did not know what to draw (Caldino, Palou, Macias, Lopez-Malo, & Garibay, 2009). Design-centered curriculum that guides students through the steps of engineering design, construction, and testing has been found effective in crossing age, gender, academic, economic and ethnic barriers and changing students’ perspectives about engineering (Caldino et al., 2009).

2.4 Models of Professional Development

Systemic educational reform, focused on improving student learning and achievement, depends upon a workforce of qualified teachers (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Loucks-Horsley, 1998; Zepeda, 2012). Teachers, more than any other factor in a school setting, significantly influence student achievement (Haney & Lumpe, 1995; National Comprehensive Center for Teacher Quality, 2011). The need for prepared and proficient educators places professional development in a nexus role for successful systemic reform and calls for a new paradigm (Loucks-Horsley, 1998; Loucks-Horsley & Matsumoto, 1999).

Professional development is integral and essential for all staff members if schools are to prepare their students for citizenship and productive employment (Zepeda, 2012). There must be a shift in the design, implementation, and evaluation of professional development to meet new demands on teachers. The “one-time, one-teacher-at-a-time, expert-driven workshop” that pulled teachers out of their classrooms is too narrow in scale, scope and duration, and out of sync

with what we know about effective professional learning experiences (Loucks-Horsely, 1998, p.3).

While it is generally accepted that efforts to improve teachers' skills and knowledge will, in turn, benefit students' learning, too many professional development experiences are disconnected from teachers' practice and incoherent with school-based improvement goals (Darling-Hammond et al., 2009; NCCTQ, 2011). Many programs fail to draw teachers into the planning for professional development experiences and minimize the process required to change teachers' practice. Teachers are practical and want experiences that can immediately impact their students' lives (Guskey, 1986). Forty-two percent of teachers surveyed in 2004 for the Teaching Commission described their professional development experiences as lacking or a waste of time. Only 18 percent within the survey indicated that the learning activities helped them become more effective teachers (NCCTQ, 2011).

High quality professional development directly impacts student learning by supporting and changing teacher practice over the long term (Darling-Hammond et al., 2009; NCCTQ, 2011). Exemplary professional development must target both individual and organizational change to sustain teacher growth and must be designed with adult learners in mind to engage and encourage teacher buy-in (Loucks-Horsely, 1998; NCCTQ, 2011).

Professional development is a complex learning science and little definitive research clearly links what is believed to be effective professional development with improvements in teaching and learner outcomes (Borko & Klingner, 2013; Garet et al., 2001; Guskey, 2003; Loucks-Horsely, 1998). However, many can agree upon some key elements of effective professional development design, implementation and evaluation.

Effective Professional Development Design

Learning Forward, known as the National Staff Development Council until September 1, 2010, is self-acclaimed as one of the nation's only professional organizations dedicated to increasing the capacity of leaders and developing and sustaining highly effective professional learning experiences to support student success (Learning Forward, 2015b). A 2009 review of teacher development, completed by this group, identified some attributes held in common within the design of effective professional development experiences (Darling-Hammond et al., 2009; Learning Forward, 2015b).

Coherent and Systemic Goals. Effective professional development should be aligned with school, state, and national reforms and an integral part of school improvement plans (Garet, et al., 2001; Darling-Hammond et al., 2009; Koba & Wojnowski, 2013; Zepeda, 2012). This work should help teachers' set their own learning goals based upon student needs as identified through data analysis (Corcoran, 1995; Koba & Wojnowski, 2013). Professional learning experiences should be rooted in teachers' curriculum frameworks and help develop teachers' practices for instruction and assessment through building their understanding of reform goals and transferring this knowledge into practical use (Garet et al., 2001; Posnanski, 2002). This work enables teachers to respond to performance standards that will result in improved student learning (Zepeda, 2012).

To keep the focus of professional development on student achievement, professional development should be framed by student data and address student learning (Boots, 2013; Learning Forward, 2015a). When professional development focuses on how students learn, instructional practices related to a particular content area, and strengthening teachers' knowledge

of specific subject-matter content, it is reasonable to tie student achievement to professional learning experiences (Koba & Wojnowski, 2013; Weiss & Pasley, 2006; Zepeda, 2012).

Job-embedded and Site-based. Job-embedded learning experiences provide teachers the platform to bring new innovations into their classroom for practice, experimentation, and iteration (Darling-Hammond, 1997; Fisher, 2005; Zepeda, 2012). Professional development has a greater impact on practice if it is an integral part of the teachers' work day (Corcoran, 1995; Learning Forward, 2015a; Sparks & Loucks-Horsley, 1989; Zepeda, 2012). Teachers need daily opportunities to reflect on context-specific challenges inherent to their classroom setting (Wayne, Yoon, Zhu, Cronen, & Garet, 2008; Zepeda, 2012). *Learning Forward* advocates for results-driven, job-embedded professional learning experiences (National Staff Development Council, 2001). Small groups such as learning communities, coaching models, study groups, critical friends groups, and book studies may help frame site-based, on-going professional learning experiences. Within these small group settings, colleagues support each other to set learning goals that focus on improving personal practice as it relates to student learning (Zepeda, 2012). Lesson studies, learning circles, action research, and portfolios are other options to frame job-embedded, daily professional learning growth (Zepeda, 2012).

Ongoing and Sustained. Professional development limited to a few in-service days a year does little to change or enhance teacher practice (Garet et al., 2001; Weis & Pasley, 2006). Effective professional development must be sustained over time (Darling-Hammond et al., 2009; Mizell, 2008; Posnanski, 2002; Sparks & Loucks-Horsley, 1989; Weis & Pasley, 2006; Zepeda, 2012). Some researchers suggest the need for 45 - 80 hours or more of focused professional development to transform teacher practice (Cotabish et al., 2013; National Science Board, 2008). Many suggest that professional learning should follow a cycle of continuous improvement that

begins by analyzing student and teacher performances to set school learning needs and define clear teacher learning goals (Darling-Hammond et al., 2009; Learning Forward, 2015a; Mizell, 2008; Sparks & Loucks-Horsley, 1989). New practices are tested and refined in context through cycles of conversation, action, and reflective feedback that sets the stage to increase content knowledge, build student conceptual understanding, and develop supportive teaching strategies (Sparks & Loucks-Horsley, 1989; Zepeda, 2012). Both a substantial time span and contact hours influence the depth of teacher change (Borko & Klingner, 2013; Corcoran, 1995; Garet et al., 2001). Effective professional development should include follow-up and continuous feedback (Darling-Hammond et al., 2009; Garet et al., 2001; Learning Forward, 2015b; NCCTQ, 2011).

Connected to Content and the Curriculum. The most effective professional development experiences are tied not only to standards, but relate specifically to the teacher's content, curriculum, and daily responsibilities (Birman, Desimone, Porter & Garet, 2000; Darling-Hammond et al., 2009; Hunzicker, 2010; Weis & Palsey, 2006; Zepeda, 2012;). Targeted professional development prepares teachers to increase their expertise in subject content and teaching strategies (Koba, & Wojnowski, 2013; NCCTQ, 2011; Zepeda, 2012). Content should be embedded within science professional development addressing both content and pedagogical content knowledge (Loucks-Horsley, Hewson, Love, & Stiles, 1998; Posnanski, 2002; Schlang, 2006). Corcoran (1995) supports these findings and suggests that professional development that addresses both how children learn and subject-matter content is more likely to change teacher practice.

Active Learning and Collaboration. Effective professional development provides educators intellectual, meaningful, and social engagement with ideas, materials, and colleagues, treating them as active learners who construct their own knowledge (Little, 1993; Wilson &

Berne, 1999). Site-based professional development provides teachers opportunities to work collaboratively, in subject-specific or grade-level teams, to develop long-term collaborations within settings that allow for informed dissent. A critical mass of teachers should be included in the training to support ongoing change and build strong support systems (Little, 1993; Zepeda, 2012).

Models of effective professional development provide teachers opportunities to explore, question and debate with one another as they integrate new ideas into their teaching practice and build a culture to support professional growth (Corcoran, 1995; NCCTQ, 2011; Zepeda, 2012). Teachers are motivated by working within a community of learners, setting the stage for active engagement in planning, practice, and targeted discussion (Darling-Hammond & McLaughlin, 1995; Darling-Hammond & Richardson, 2009; Loucks-Horsley, et al., 1998; Zepeda, 2012).

Treating Teachers as Professionals. Professional development should help teachers find their voices to direct their own learning, treating teachers as professionals and encouraging them to set their own learning objectives (Koba, & Wojnowski, 2013; Wilson & Berne, 1999; Zepeda, 2012). Effective professional learning experiences guide teachers through an inquiry process of learning, respecting the leadership and intellectual nature of teachers and principals (Zepeda, 2012). Teachers are empowered to facilitate change, not seen as targets of change (Koba & Wojnowski, 2013; Sparks & Loucks-Horsely, 1989). Where possible, teachers within the system should plan and facilitate their own professional learning experiences (Weis & Pasley, 2006).

Comprehensive Models. Haney and Lumpe (1995) developed a three-step framework, that incorporates planning, training, and follow-up, based upon a synthesis of emerging ideas from research on the status of science teaching, theories, and teacher needs assessments. This

model, depicted in Figure 1, advocates for planning professional learning experiences that are concrete, teacher-specific, and extend over time. They suggest building teacher leadership teams that not only include influential teachers, but also the building principal and community representatives.

Planning within this framework targets working with a critical mass of teachers within a school and stresses the importance of planning regular meetings with the leadership team. Teachers are empowered within this model, being included in decision-making that stresses self-reflection and continuous feedback among peers. The planning component of Haney and Lumpe’s framework is built upon a broad research base (Fullan & Miles, 1992; Glickman, Hayes, & Hensley, 1992; Hord & Austin, 1988; Keller, 1995; Maehr, Midgley, & Urden, 1992; McLaughlin, 1990; Valencia & Killion, 1988; as cited by Haney & Lumpe, 1995). This approach to planning professional learning experiences has been reinforced by more recent research supporting job-embedded learning experiences that include teachers in decision-making (Darling-Hammond, 1997; Fisher, 2005; Wayne et al., 2008; Zepeda, 2012).

The training stage of Haney and Lumpe’s model places teachers in professional learning experiences that focus on reform issues, such as the need for inquiry and design-based planning and teaching. Teachers engage in activities that model how they should teach, have time to observe peers, and opportunities to develop and select

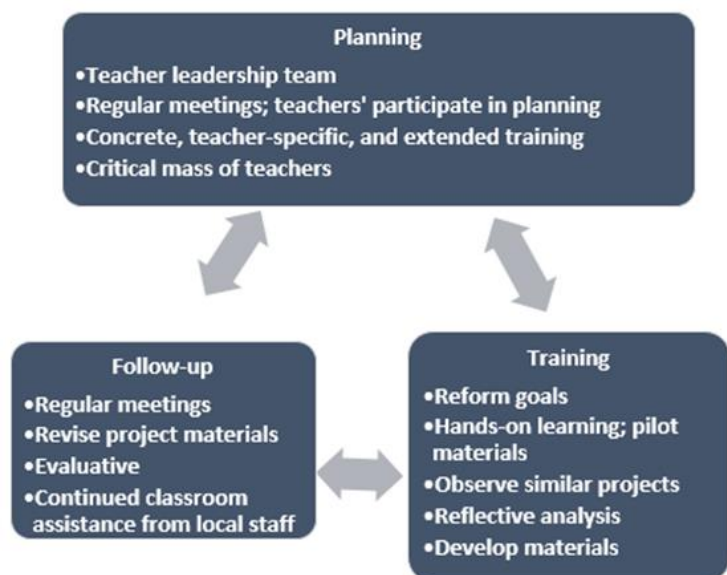


Figure 1: 1995 Haney and Lumpe Model of Professional Development

curricula materials. Reflective analysis is embedded within this stage. The underpinning elements of the training component of this model are well supported by research (Bandura (1986); Etchberger & Shaw (1992); Hunsaker & Johnson (1992); Richardson (1990); as cited by Haney & Lumpe, 1995). These tenants continue to rise to the top of best practice approaches to planning through active learning and collaboration (Little, 1993; Zepeda, 2012).

The follow-up stage within Haney and Lumpe's framework provides continued reflection and on-going support from school-based personnel. Project materials are revised and refined and the training group continues to meet on a regular schedule (Haney & Lumpe, 1995). The third and final component of Haney and Lumpe's model is also supported by research (Glickman, et al., (1992); Hunsaker & Johnson (1992); McLaughlin (1990); Shroyer (1990); Tobin & Espinet (1989); Valencia & Killion (1988); as cited by Haney & Lumpe, 1995). Once again, Haney and Lumpe's original work continues to be supported by more recent research advocating a coherent and sustained approach to professional development that addresses systemic goals (Garet et al., 2001; Darling-Hammond et al., 2009; Koba & Wojnowski, 2013; Zepeda, 2012).

Borko and Klingner (2013) support the use of the Problem-Solving Cycle (PSC) as the basis of iterative, long-term, mathematics professional development. Similar to Haney and Lumpe's model, the PSC empowers teachers to build their content knowledge through active strategies and encourages teachers to use their own classrooms as the context for learning. Teachers work in collaborative communities of practice, participating in a series of interconnected PD around targeted math tasks (Borko & Klingner, 2013).

Guskey's Model of Teacher Change places teachers in the center of planning and builds professional development around instructional gaps identified by teachers (Guskey, 1985). Guskey suggests that significant change in teachers' attitudes regarding professional

development innovations occurs only after teachers see evidence of these innovations improving their students' learning. Successful implementation of new teaching innovations makes believers out of teachers and more quickly changes their attitudes about embracing new strategies or innovations (Guskey, 1985, 1986, 1989). PSC, Haney and Lumpe's and Guskey's models all place teachers at the center of professional development planning, implementation and evaluation (Borko & Klingner, 2013; Guskey, 1985; Haney & Lumpe, 1995).

Effective Professional Development Implementation

Planning effective professional development sets the stage for implementing effective professional development. As described earlier within this chapter, effective professional development should be ongoing and extend over time (Darling-Hammond et al., 2009; Mizell, 2008; Posnanski, 2002; Sparks & Loucks-Horsley, 1989; Weis & Pasley, 2006; Zepeda, 2012), actively engage teachers through constructivist learning (Little, 1993; Wilson & Berne, 1999) and support collaborative environments (Darling-Hammond & McLaughlin, 1995; Darling-Hammond & Richardson, 2009; Loucks-Horsley, et al., 1998; Zepeda, 2012).

Facilitation and Reflection. In addition to the stated best practice considerations for designing effective professional development, those implementing professional development should take the role of consultant or facilitator (Koba & Wojnowski, 2013; Zepeda, 2012). Professional learning experiences should be run by administrators and teacher leaders, not outside experts (Zepeda, 2012). This provides continuous improvement for all who are involved in site-based student learning. Variety and multiple modalities of learning are also important to support active teacher engagement (Koba & Wojnowski, 2013).

Effective professional development implementation guides teachers through reflection during and after professional growth experiences (Corcoran, 1995; Koba & Wojnowski, 2013;

Zepeda, 2012). Teachers become reflective practitioners utilizing cycles of learning, implementation, and reflection (Koba & Wojnowski, 2103; Posnanski, 2002).

Effective Professional Development Evaluation

It is important to evaluate professional learning experiences to determine what works and why, and whether intended results are realized (Zepeda, 2012). The National Comprehensive Center for Teacher Quality (NCCTQ) (2011) claims that there are few high-quality evaluations of professional development programs. This is due, in part, to the fact that evaluating the impact of professional learning activities on teacher practice and/or student learning is difficult, time-consuming, and expensive. Killion (2002) suggests that an effective professional development plan must have a clear, logical theory of change, increase the likelihood of change in student learning, and collect relevant data that results in useful evaluation. Aubel (1999) describes the benefits of evaluation as a process that transfers lessons learned into an institutionalized use of information that can be applied to future professional learning experiences. Including the teachers in the evaluation process mirrors the job-embedded approach to professional growth (Zepeda, 2012). Evaluation should not be seen as punitive, but a way to identify what is working through purposeful learning. Two noted evaluation models are described in the next section.

Kirkpatrick and Kirkpatrick's Model. Kirkpatrick and Kirkpatrick's Model (1994) identifies four levels to evaluating the effectiveness of professional development in response to changing teacher practice. At the lowest level (Level 1) teachers' reactions to training are measured. Teachers are asked if they felt that the training was relevant and whether or not they liked the training. Level 2 measures changes in teachers' knowledge, skills, and/or attitudes through pre- and post-testing assessments. If professional development impacts teacher learning at a Level 3, teachers demonstrate that they can put what was learned into action in their

classroom. The highest level within Kirkpatrick and Kirkpatrick's Model, Level 4, measures if there are changes in student achievement based upon changes in teacher practice (Kirkpatrick & Kirkpatrick, 1994).

Guskey's Levels of Evaluation. Guskey (2000) expanded the Kirkpatrick and Kirkpatrick Model to five levels of evaluation for professional development. His levels 1 and 2 directly mirror the Kirkpatrick and Kirkpatrick Model. Guskey's Level 3 considers the support needed for teachers from their principal, school, or district, noting that individual change must be supported and sustained at an organizational level. The desired impact requires organizational commitment to facilitate implementation. Levels 4 and 5 mirror Kirkpatrick and Kirkpatrick's Levels 3 and 4, evaluating whether the professional growth experiences are being implemented in the classroom and, due to this implementation, how student learning outcomes are impacted by these changes (Guskey, 2000, 2002).

Guskey (2002) has also noted that it may be prudent to plan professional development backwards, beginning with the desired changes in student practice as the goal to define the needs of effective professional learning experiences. His work emphasizes practical evaluations that are, by design, not complicated or burdensome. According to Guskey, evaluation is a step-by-step, focused, and intentional process that produces data that can be used to make thoughtful and responsible decisions about the processes and effects of professional development (Guskey, 2000, 2002; Zepeda, 2012).

Importance of Effective Professional Development

Current professional learning experiences focus on facilitating teacher learning within the context of classroom setting, organized around content and authentic activities specific to that setting (Putnam & Borko, 2000). The NCCTQ (2011) suggests that quality professional

development, while necessary for all, is most essential to build equity amongst teachers working with poor and minority students. This group notes that “poor and minority students are more likely to be assigned teachers who have less experience and who are teaching out of their field” (NCCTQ, 2011, p. 1). With this in mind, raising the level of teacher professional development for all has the potential to reduce the wide range of teacher abilities, and, ultimately reduce inequity for students as a result of poorly prepared teachers (NCCTQ, 2011). *Learning Forward* emphasizes that professional learning experiences should support collective responsibility for improved student performance by developing teams of educators who approach professional growth collaboratively (Mizell, 2008). NCCTQ (2011) cites growing evidence that effective and “meaningful professional development could help recruit and retain teachers in hard-to-staff schools” (p. 2).

Within the status report on teacher development conducted by the National Staff Development Council in 2009, now *Learning Forward*, less than one-fourth of teachers surveyed felt as if their voice was heard in making school decisions and policies. While a slim majority of teachers across the nation indicated feeling as if they were influential in curriculum matters and setting student performance standards, fewer than half indicated that they had some control over the content of their professional development (Darling-Hammond et al., 2009). If teacher development is designed to support a teacher’s continuous practice of inquiry, teachers need a voice in crafting professional development and should be considered reflective practitioners with the knowledge base to construct and reconstruct knowledge (Posnanski, 2002). *Learning Forward’s* (2015a) definition of professional development begins with an explicit description of the school-based infrastructure needed to organize and implement professional learning experiences to increase student achievement, soundly placing confidence in educators and

supporting the belief that educators should be empowered to define their own learning goals based upon the needs of their students. Professional growth is an active process where educators learn through implementing evidence-based strategies and assist in the assessment of the effectiveness of their professional learning experiences (Mizell, 2008).

2.5 Adult Learning Theory

Much of the literature addressing adult learning theory points to Malcolm Knowles as the honorary father of adult learning. Knowles' early work delineated differences between pedagogy (methods of teaching children) and andragogy (methods of teaching adults), defining andragogy as a systematic and purposeful approach to guiding adult learning and helping adults focus on applying knowledge to real life settings (Forrest & Peterson, 2006; Knowles, 1977; Terehoff, 2002).

Knowles' Foundational Tenants

Knowles (1977), and then again Knowles with Holton and Swanson (1998), described several foundational tenants for adult learners. The first four listed below were Knowles' original work, with the last two additions from his later collaborative work with Holton and Swanson (Knowles et al., 1998, p. 64-68):

- 1) The Need to Know: Before committing to learning, adults need to know why they are learning what they are learning;
- 2) The Learner's Self-Concept: Adults have a strong sense of self and adult learning is, primarily, self-directed and a choice;
- 3) The Role of the Learners' Experiences: Adults bring varied backgrounds to learning and attention should be given to this previous experience when groups design and deliver instruction;
- 4) Readiness to Learn: An adult's readiness for learning is determined by their need for that information or experience;
- 5) Orientation to Learning: Adults respond to problem-centered or life-centered learning situations; and
- 6) Motivation: Internal factors are more motivating for adults than external factors

These theoretical tenants stress the importance of acknowledging and incorporating an adult learner’s background and life experiences into promoting new ways of thinking and reasoning (Terehoff, 2002). They also emphasize that adult learners need buy-in to new innovations and should be part of the decision making that frames their learning experiences, making decisions about the setting, planning, goals, objectives, and assessment. Adults’ needs and interests should be considered, honoring their years of experience. Knowles’ approach suggests that adult learning should be problem, or life-centric and that adults, when appropriately motivated, are self-directed learners (Knowles et al., 1998; Terehoff, 2002).

Rogers Innovation-Decision Process

While Knowles’ work is foundational within the realm of adult learning, Rogers’ Diffusion Theory is often referenced to describe the process of how people accept innovations or acquire new knowledge (Fisher, 2005; Knowles, 1977; Rogers, 1983; Rogers, 2003). Within this theory, Rogers’ innovation-decision process describes the procedure individuals work through to gain knowledge about an innovation and, ultimately, accept that innovation. There are five stages to the model: Knowledge, Persuasion, Decision, Implementation, and Confirmation (Fisher, 2005; Rogers, 1983). These stages are outlined in Table 2.

Table 2
Rogers Innovation-Decision Process

Knowledge	Knowledge occurs when an individual is exposed to an innovation’s existence and gains an understanding of how it functions.
Persuasion	Persuasion occurs when an individual forms a favorable or an unfavorable attitude towards the innovation.
Decision	Decision takes place when an individual engages in activities that lead to a choice to adopt or reject the innovation.
Implementation	Implementation occurs when an individual puts a new idea into use.
Confirmation	Confirmation takes place when an individual seeks reinforcement of an innovation-decision already made, but he or she may reverse this previous decision if exposed to conflicting messages about the innovation.

Rogers suggests that sustaining the use of an innovation is the goal for learning, with the highest level demonstrated when an individual re-invents or adapts an innovation to tailor it to his/her needs (Fisher, 2005; Rogers, 1983). Rogers' model, when applied to effective professional learning experiences within education, is demonstrated as acquiring, using, and incorporating new knowledge.

Self-directed and Authentic Learning.

Self-directed learning, for adults, is often paired with personal responsibility and situates the learner to select what to learn, how to interact with the information, and how to apply the learning as needed (Gammill, 2013). It is purposeful and organized with an end goal in mind. Newsom (1977) has likened self-directed learning to life-long learning and Gibb (1960) confirms Knowles' approach that adult learning must be problem-centered, experiential, and meaningful. Self-directed learning is driven by reflection and often leads to changes in paradigms and practices (Gammill, 2013). Adults take the initiative for their learning and often seek collaborative social interactions (Drago-Severson, 2011; Gammill, 2013; Young, 2005).

Ashton's (2010) review of five adult learning studies questions what the term authentic learning means when applied to adult learners. His theoretical work suggests that authentic learning emphasizes the adult's frame of mind, not the learning experience or context. Using the phrase authenticity-in-learning, Aston suggests that the adult "chooses to bring authenticity to their learning" and further describes adult learners as placing themselves in a "being mode" where "learning is a process of critically reasoning" and adults in this mode "relate and interact with the world" by creating meaning and making it their own (Ashton, 2010, p. 7 & 13). Ashton counters this with child-like learning where learners seek accepted answers. Adult learners

reflect and compare learning with past experiences to bring personal significance to their learning.

To support this level of adult learning, facilitators must raise the learner's awareness and create a learning environment where the adults are fully present with a desire to commit to the process (Ashton, 2010). From his review of authenticity, Ashton suggests that adult learners need settings that acknowledge and embrace their sense of self, values, and principles. Adult learners accept responsibility for their own learning and need to be open to the possibility of learning and understanding in new ways.

Separations Between Adult Learning and Other Levels of Learning

Knowles placed pedagogical and andragogical learning on a continuum, suggesting that one key difference between the needs of student and adult learners focused on the adult learner's need for relevance for learning and a connection between prior experiences and new learning (Knowles et al., 1998). While others agree that adults need to build their own understanding and meaning from new learning experiences, constructivist theory questions if this approach is true only for adult learners (Young, 2005). Students also need relevance for their learning and pre-assessment that builds prior knowledge into instruction (Forrest & Peterson, 2006; Ormond, 2014; Uden & Beaumont, 2006).

It would seem that the greater difference between adult and student learners is characterized by the learner's motivation for learning (Forrest & Peterson, 2006). Instructors, through the role of facilitators, help guide adults' learning, but the motivation to learn is often a result of the adult learners' self-identified interests and needs. Ultimately, the responsibility for learning falls on the adult's shoulders (Gammill, 2013). Knowles (1977) boldly stated that pedagogy was not learner-centered, but focused on the instructor's delivery of subject matter.

Admittedly, no matter how engaging the learning, students are captive audiences, mandatorily sitting in classrooms. Boyer (1984) compared Knowles assumptions about andragogy with Carl Rogers' suggestions about student-centered learning. In the late 1960's, Rogers took an early view of student-centered, self-initiated learning promoting a theory that encouraged student-centered inquiry for students of all ages (Boyer, 1984; Rogers, Lyon, & Tausch, 2013). Knowles and Rogers' approaches both set lifelong learning as a central goal for education, promoting learning as the tool to facilitate change and focusing on the process of learning, not discrete and discrepant facts (Boyer, 1984; Rogers et al., 2013).

Adult Learning Theories Impacting Teacher Learning Experiences

Accepting and embracing new educational practices is often difficult for educators (Fullan, 1991). The change process for adults is slow and even moderate change may require three-to-five years of gradual and persistent efforts. Small changes build upon each other, pushing teachers towards new professional paradigms through stages of re-culturing (Fullan 2001). The re-culturing process is fueled by changes in teachers' knowledge, practices, and roles and often best supported within school settings through professional learning communities within a community of practice (Young, 2005).

Knowles' Principles for the Andragogical Teacher, listed in Table 3, frame similar expectations cited as best practice teacher professional development, discussed earlier in this chapter (Knowles et al., 1998, p. 93-94). Best practice research within professional development aligns with many of the theories of andragogy described by Knowles. Teachers, as adult learners, want to immediately apply what they learn to improve their classroom (Zepeda, 2015). Teachers seek relevance and flexibility in their learning. They want to interact with content and seek opportunities for self-reflection.

Table 3

Andragogical Teacher and Best Practice Professional Learning

Principles for the Andragogical Teacher	Professional Learning Attributes Described in Section 2. 4
Learners feel a need to know.	Coherent and Systemic Goals; Job-embedded; Connected to Content and Curriculum
Learning environment is characterized by physical comfort, mutual trust and respect, mutual helpfulness, freedom of expression, and acceptance of differences.	Active Learning and Collaboration; Treating Teachers as Professionals;
Learners perceive the goal of the learning experience to be their goals.	Job-embedded and Site-based; Connected to Content and the Curriculum;
Learners accept a share of the responsibility for planning and operating a learning experience, and therefore have a feeling of commitment toward it.	Collaboration; Facilitated, Not Taught; Reflection and Follow-up
The learning process is related to and makes use of the experience of the learners.	Job-embedded and Site-based
The learners have a sense of progress toward their goals	Ongoing and Sustained; Reflection and Follow-up

2.6 The McDaniel College Elementary STEM Instructional Leader Program

McDaniel College’s ESIL graduate program was developed collaboratively by McDaniel College, CCPS and NIA-CISE in response to a solicitation from MSDE (MSDE, 2012). This call encouraged higher education institutions to design and implement coursework for elementary pre-service and in-service teachers that would prepare elementary teachers to plan and teach STEM-centric lessons and lead to earning MSDE’s Instructional Leader: STEM (PreK-6) endorsement. A minimum of 18 semester hours addressing STEM content, practices, and curricula pedagogies are required by MSDE for teachers to earn the Instructional Leader endorsement (MSDE, 2013a).

The six graduate courses within the ESIL program are listed in Table 4. Elementary teachers from CCPS were the first cohort to pilot these courses, and completed all coursework and requirements for the Instructional Leader endorsement in the summer of 2015. Three additional CCPS cohorts are in various stages of completing the ESIL program at this time.

Table 4

Elementary STEM Instructional Leader (ESIL) Coursework

STM 501	Practical Applications for STEM Education
STM 502	STEM Education Roots
STM 503	STEM Education Issues and Trends
STM 504	STEM Education Methods and Materials
STM 505	Facilitating STEM Education Professional Learning Experiences
STM 506	STEM Education Practicum

Design of the Graduate Courses

The McDaniel College ESIL courses are designed to build elementary teachers’ competence in STEM content and practices (McDaniel, 2015a). Aligned with the *NGSS*, *STL*, and *Maryland’s STEM SOP*, these courses prepare elementary teachers to create inquiry- and design-based 7E learning cycle constructivist lessons. Teachers learn how to implement science and engineering practices by hands-on, active learning. The ESIL courses transform elementary teachers’ planning.

All of the ESIL courses are hybrid courses, integrating online and face-to-face instruction (McDaniel, 2015a). Each course begins and ends with asynchronous online interactions, allowing the instructor to pre-assess the group’s understanding of concepts prior to face-to-face meetings and share products and reflections following lesson implementation. By blending online and face-to-face instruction, the ESIL courses are tailored to meet teachers’ busy schedules, pull in resources that are not local, and offer job-embedded support (Dede, 2006). Online, asynchronous discussions promote self-reflection, asking the teachers to analyze and consider what is being learned (Almendarez-Cadena, 2014; Dede, Ketelhut, Whitehouse, Breit, & McCloskey, 2009). Digital tools and platforms enable the teachers to collaborate, share resources, and openly reflect with each other (Zepeda, 2015).

Each course introduces and reinforces integrative standards-based science, technology, engineering, and mathematics content and practices, addressing elementary teachers’

misconceptions and, sometimes, gaps of knowledge within STEM disciplines (McDaniel College, 2015a). Beginning with *STM 501: Practical Applications of STEM Education* and reinforced within *STM 502: STEM Education Roots*, teachers learn how to plan lessons that incorporate both inquiry and design-based instruction (Bowers, 2015a; Bowers, 2015b). From the start, teachers develop individual systems for integrating the use of STEM notebooks into science and math instruction. Lesson design follows the tenants of problem-based learning organized within the 7E Learning Cycle. An engineering design problem engages students within the Engage step, the first “E” of each 7E lesson. This lesson model promotes student-centered learning driven by students generating questions (Bybee, 1997; Bybee et al., 2006). Teachers develop a library of 7E lessons that are not only aligned with the national reform *NGSS*, *STL*, and *Common Core State Standards for Math*, but deliberately introduce *Maryland’s State STEM SOP* (Bowers, 2015a).

STM 503: STEM Education Issues and Trends challenges teachers to identify current issues within STEM education and develop an action plan to address this issue close to home in their classroom or school setting (Bowers, 2015c). *STM 504: STEM Education Methods and Materials* guides teachers through the development of a 7E STEM module, reinforcing their understanding of problem-based, design-based and inquiry instruction as well as their proficiency in integrating STEM content and practices (Bowers, 2015d). *STM 505: Facilitating STEM Education Professional Learning* guides the participants in the development and facilitation of their own hybrid STEM professional development (Bowers, 2015e). The final course, *STM 506*, is the *STEM Education Practicum* (Eckenrode, 2015). Within this course, participants complete additional field experience working with students and teachers at various grade levels to hone their STEM leadership skills.

Elements of the Haney and Lumpe Model for Professional Development, and cited best practice choices for adult learners and the design and facilitation of professional development, were used to frame the McDaniel College ESIL model. The collaborative relationship among McDaniel College, CCPS, and the NIA-CISE creates a powerful leadership team primed to differentiate instruction to meet the specific needs of elementary teachers within the county system (Borko & Klingner, 2013; Haney & Lumpe, 1995). Coursework introduces and reinforces coherent state and national systemic goals, helping teachers interpret, decipher, and utilize these reform documents (Garet, et al., 2001; Darling-Hammond et al., 2009; Koba & Wojnowski, 2013; Zepeda, 2012).

Teachers within the ESIL program work through the series of courses as a cohort, building a critical mass newly trained to infuse learning throughout the school system (Haney & Lumpe, 1995). The development of the 7E lessons and use of STEM notebooks are integrated directly into each teacher's instruction, connecting learning to content and system-based curriculum (Birman et al., 2000; Darling-Hammond et al., 2009; Hunzicker, 2010; Weis & Palsey, 2006; Zepeda, 2012). The 7E curricular model has been embraced by CCPS curriculum specialists and has become the model of choice for curriculum design across the county.

Respecting the teachers as adult learners is an essential component within the McDaniel College ESIL model. Teachers choose to participate within cohorts, recognizing their own "need to know" before committing to learning (Knowles, 1977; Knowles et al., 1998). Their prior experiences are valued and all tasks within the coursework result in immediate and practical application within their classrooms (Darling-Hammond, 1997; Knowles et al., 1998; Zepeda, 2012). The ESIL coursework is paced to provide ongoing and sustained professional growth for the cohort of teachers, following a model of continuous improvement (Darling-Hammond et al.,

2009; Learning Forward, 2015a; Sparks & Loucks-Horsley, 1989). The hybrid model supports an ongoing network and learning community (Dede, 2006). Face-to-face instruction is constructivist, providing teachers an opportunity for hands-on, active learning (Little, 1993; Wilson & Berne, 1999).

Teachers within the ESIL program complete six MSDE-approved Key Assessments at set junctures within the coursework to assess their STEM content knowledge, their abilities to plan STEM-centric lessons, their abilities to assess student growth, and their STEM leadership skills with students and teachers (McDaniel, 2015a). These performance assessments were developed iteratively between administrative teams from McDaniel College and the MSDE’s Elementary STEM Certification Program. Each assessment addresses particular *Maryland State STEM SOP* and includes a task description and analytic rubric. The key assessments are listed within Table 5.

Table 5
ESIL Key Assessments

Key Assessment	Assessment Focus	Maryland STEM Standards of Practice (SOP)
1	Content Based Assessment	SOP 1, SOP 2, SOP 3, SOP 4, SOP 5, SOP 6, SOP 7
2	Content Knowledge	SOP 1, SOP 2, SOP 5
3	Competence in Planning	SOP 2, SOP 4, SOP 6, SOP 7
4	Practicum	SOP 6
5	Candidate Effect on Student Learning	SOP3, SOP 5
6	STEM Instructional Leader	SOP 1, SOP 2, SOP 3, SOP 4, SOP 5, SOP 6, SOP 7

Teacher content knowledge is verified within *Key Assessments 1* and *2*. *Key Assessment 3, Competence in Planning*, asks teachers to dissect and reflect upon the underlying planning within a 7E lesson. *Key Assessments 4* and *6* ask the teachers to reflect on their practicum experience and growth as a STEM instructional leader. *Key Assessment 5* is a case study

profiling the effect STEM-centric teaching has had in reference to a particular student's learning. All six assessments are organized within a digital portfolio and submitted as evidence of growth for the MSDE Instructional Leader: STEM (PreK-6) endorsement.

Key Assessment 3 is the instrument used within this study and the assessment that focuses on the teachers' competence in planning STEM-centric instruction. Planning links curriculum and instruction, outlining effective teaching that impacts student learning (Richard, 2004; Wing-mui So, 1997). Planning may vary with teacher experience (Borko & Niles, 1987). As teachers plan, they must balance cognitive goals and subject matter (Borko & Shavelson, 1983). Elementary teachers are often more concerned with content than the structure of the subject matter, frequently turning to textbooks as their major source of content (Borko & Shavelson, 1983). Elementary teachers completing courses within the ESIL program learn to move away from a dependence on textbooks to develop design-based, 7E lessons that integrate science, technology, engineering, and mathematics (McDaniel, 2015a).

Factors Impacting Teacher Success

Various factors impact the success of elementary STEM educators. The teacher-learning frameworks, described to this point, require a new role for administrators. Professional development connected with student learning demands leaders who create and support infrastructures that allow site-based, on-going learning and leading (Learning Forward, 2015a; Loucks-Horsley, 1998). Such infrastructures support changes in teacher practice within collaborative group settings that build capacity for teacher leadership (Loucks-Horsley, 1998). Zepeda (2012) stresses the need for administrators to develop a supportive learning culture for teachers in their building, creating an environment that provides continuous growth for teachers as adult learners and a setting where students' and teachers' learning is a priority. There must be

resources and time within the regular school day set aside for professional learning experiences (Zepeda, 2012).

Schools must value experimentation within teaching and encourage growth through collaboration (Loucks-Horsley, 1998). Administrators must help their staff cut through the noise and develop their own voice (Tallerico, 2005; Zepeda, 2012). For this to happen, school leaders must become strong instructional leaders prepared to work with their staff to support a culture and disposition for continuous professional learning, balancing pressure and support for ongoing change (Darling-Hammond et al., 2009; Weis & Palsey, 2006).

Teachers' experiences are also factors to consider for successful adoption of new teacher practices. Teacher experience has been seen to not only impact teachers' planning (Borko & Niles, 1987), but also affect elementary teachers' familiarity and perceptions regarding design, engineering, and technology (Hsu et al., 2011). Elementary teachers are generalists, often lacking coursework as undergraduates or graduates in science and engineering (Trygstad, 2013). An elementary teacher's knowledge of science has been identified as one factor that affects lesson planning (Wing-mui So, 1997). Elementary teachers who pursue professional growth through advanced studies often have diverse experiences that include teaching at different grade levels and involvement in professional committees (Burger, 1988).

2.7 Contribution of This Study

This review surveys what is known about adult learning, best practice professional development for educators, and elementary curricular models that support inquiry- and design-based lessons framed by the science and technology national and STEM state standards. This foundational knowledge frames the design of McDaniel College's ESIL graduate coursework developed to prepare elementary educators for the task of planning STEM-centric lessons. This

study will contribute to the research by gathering data that may suggest that the design of this coursework prepares elementary educators to proficiently plan STEM-centric lessons. These findings may help inform future professional development experiences that address elementary educators' preparation to plan lessons that incorporate the *NGSS* science and engineering practices and *Maryland's State STEM SOP*.

2.8 Summary

National and state educational reforms call for changes in science instruction that require planning lessons that integrate science and engineering practices, and, in some states, STEM standards of practice. For elementary teachers, instruction will need to change dramatically and teachers will need time and support to transform their planning and teaching (NRC, 2015).

PBL, PjBL, integration, and learning cycles are all viable curricula models to consider when planning inquiry- and design-based STEM-centric lessons and units. Professional learning experiences to support transformational changes in elementary teachers' learning practices should be: (1) coherent, systemic and tied to reform documents; (2) content specific; (3) job-embedded; (4) ongoing and sustained; (5) model active learning; (6) collaborative; and (7) encourage reflective practice.

Professional development, following this design and in the form of coherent graduate coursework, can prepare elementary teachers to plan lessons that support reformed science instruction. Chapter 3 discusses the methodology used to determine if teachers completing such graduate coursework have built proficiency in expected lesson design.

CHAPTER 3: METHODOLOGY

The purpose of this study was to investigate the ability of elementary teachers to proficiently plan STEM-centric lessons, defined by MSDE as lessons or units that incorporate the *Maryland State STEM SOP* (MSDE, 2013b). The study used a state-approved assessment task and rubric, identified as *Key Assessment 3*, to gather data from the sample population's digital portfolios. *Key Assessment 3: Competence in Planning* focuses on teacher planning. The sample population was from the first cohort of teachers completing the teacher planning assessment tasks for CCPS. A test of hypothetical value was conducted using the nonparametric Wilcoxon-signed-rank Test. Three independent assessors were trained to use the state-approved rubric accompanying *Key Assessment 3*. Consensus estimates were compared using Fleiss' kappa statistic seeking interrater agreement ≥ 0.90 among the assessors. This chapter includes descriptions of the design used for the study and the study's sample. The tools used in the study and statistical analysis methods used to assess the hypotheses are also discussed.

3.1 Research Hypotheses

The research hypotheses for this study were based upon four research questions and assisted in exploring whether teachers in the McDaniel College's first ESIL cohort demonstrated proficient abilities in planning STEM-centric lessons. The lessons reviewed address four of the seven *Maryland State STEM SOP*: (*SOP2*) *Integrate Science, Technology, Engineering, and Mathematics Contents*; (*SOP4*) *Engage in Inquiry*; (*SOP6*) *Collaborate as a STEM Team*; and (*SOP7*) *Apply Technology Strategically*. *Key Assessment 3: Competence in Planning*, one of six state-approved assessment tools, was used to gather data for this study.

The hypotheses derived from the research questions are:

RQ#1: To what extent are teachers within the McDaniel College pilot cohort proficient in

developing lessons that **integrate science, technology, engineering, and mathematics disciplines?**

RQ1 – H₁: Teachers within the McDaniel College pilot cohort are proficient or exemplary in developing lessons that *integrate science, technology, engineering, and mathematics disciplines*.

RQ1 – H_A: Teachers within the McDaniel College pilot cohort are less than proficient in developing lessons that integrate science, technology, engineering, and mathematics disciplines.

RQ#2: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that **engage students in inquiry?**

RQ2 – H₁: Teachers within the McDaniel College pilot cohort are proficient or exemplary in developing lessons that engage students in inquiry?

RQ2 – H_A: Teachers within the McDaniel College pilot cohort are less than proficient in developing lessons that engage students in inquiry.

RQ#3: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that **support student collaboration as a STEM team?**

RQ3 – H₁: Teachers within the McDaniel College pilot cohort are proficient or exemplary in developing lessons that support student collaboration as a STEM team.

RQ3 – H_A: Teachers within the McDaniel College pilot cohort are less than proficient in developing lessons that support student collaboration as a STEM team.

RQ#4: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that **support students' strategic application of technology?**

RQ4 – H₁: Teachers within the McDaniel College pilot are proficient or exemplary in developing lessons that support students' strategic application of technology.

RQ4 – H_A: Teachers within the McDaniel College pilot cohort are less than proficient in developing lessons that support students' strategic application of technology.

3.2 Research Design

The purpose of this research was to add to the field's knowledge of elements in the promotion of graduate coursework that leads to elementary in-service teachers' proficiency in planning STEM-centric lessons. The methods of analysis used in this study included a test of

hypothetical value, conducted using the nonparametric Wilcoxon-signed-rank Test, and assessor interrater reliability, assessed using the Fleiss' kappa statistic.

McDaniel College Graduate and Professional Studies, in partnership with CCPS and NIA-CISE, developed a series of six graduate courses that comprise the McDaniel College ESIL graduate program. This coursework was designed and developed collaboratively with the CCPS elementary science coordinator and CCPS STEM specialist to assure alignment with CCPS and Maryland STEM education initiatives. In addition to designing the courses, the elementary science coordinator co-instructed five of the six pilot courses, and was the sole instructor for the final practicum. The CCPS STEM specialist attended most face-to-face sessions and based CCPS curriculum design on lessons learned throughout the ESIL program. Completion of the ESIL coursework fulfills the requirements outlined by MSDE for teachers to earn the Instructional Leader: STEM (PreK-6) endorsement (MSDE, 2013a). While a new area of endorsement, this accreditation may lead to a variety of teacher leadership opportunities within STEM education that include, but are not limited to, serving districts as STEM specialists, STEM coordinators, STEM educators, STEM curriculum developers, and local education agency professional development provider capacities.

In addition to completing the six courses, candidates for the MSDE Instructional Leader STEM (PreK-6) endorsement must also complete six key assessments that document, assess, and verify the teachers' proficiency in elementary STEM content knowledge, planning STEM learning experiences, assessing student learning, and fulfilling a variety of STEM leadership roles (MSDE, 2003). The six key assessment tasks and rubrics incorporate the *Maryland State STEM SOP* and are completed within the graduate coursework, culminating with the final course that is the STEM Education Practicum. All key assessments are organized within the candidate's

STEM Leader Digital Portfolio (MSDE, 2013a). Performance assessments, such as MSDE's key assessments, have been incorporated into high-stakes decision testing programs like the National Board for Professional Teaching Standards (Johnson, Penny, & Gordon, 2000). These assessment tools help determine whether advanced certification, such as an additional endorsement for teaching licensure, should be awarded to a candidate.

3.3 Sample

Thirty-five CCPS teachers, identified by their administration and the county's central office for their leadership skills, were invited to join the first McDaniel College ESIL cohort the summer of 2012. Through attrition, due to changes in placements and time constraints, sixteen of the original thirty-five teachers, completed all six required courses, finishing their practicum and MSDE digital portfolios in July 2015. This group was the first group of teachers from McDaniel College to seek the MSDE Instructional Leader: STEM (PreK-6) endorsement and the first group to be assessed using the state-approved key assessments. Teachers must earn a *proficient* or *exemplary* rating on each of the key assessments to earn this endorsement.

This sample included first through fifth grade teachers. Demographic data, including gender, years of teaching experience, current grade taught, undergraduate and graduate degree, and leadership roles, was made available to the researcher from the practicum instructor who gathered this information electronically. Screenshots of the survey form are found in Appendix F. These specific demographic data were targeted based on the work and recommendations of Borko & Niles, 1987; Burger, 1988; Hsu et al., 2011; Trygstad, 2013; Wing-mui So, 1997.

3.4 Instrumentation

Elementary teachers, as a group, hold some pedagogical beliefs inconsistent with current science reform and what is known about effective science instruction (Trygstad, 2013).

Throughout the ESIL coursework, elementary teachers learned how to design lessons that are student-centered, provide hands-on inquiry-based explorations, and integrate STEM content and STEM practices, as described by the *NGSS*, *STL*, and *Maryland State STEM SOP* (Achieve, 2015b; ITEA, 2000; MSDE, 2012; McDaniel, 2015a).

Key Assessment 3: Assessment of Competence in Planning is the task and associated rubric used to examine teachers' abilities to design STEM-centric lessons (McDaniel, 2015b). This assessment was developed collaboratively between a McDaniel College administrative program development team and the MSDE's Elementary STEM Certification Program Manager and Program Approval Specialist, and is the primary instrument used to gather data for this study.

The rubric for *Key Assessment 3* is a full-model, analytic rubric. This rubric was designed as a scoring tool to describe the level of performance regarding teachers' planning. Full-model rubrics include target indicators, or essential tasks, aligned with levels of performance (Oakleaf, 2009). Analytic rubrics analyze components of a product separately, assessing specific essential traits with a separate score for each trait (Maki, 2010; Mearman, 2013; Oakleaf, 2009). The separate scores are totaled for a final score. By incorporating a more focused scoring process, analytic rubrics are more likely to be reliable than a holistic rubric. Holistic rubrics result in one score for the product based on overall impressions of the work. They are considered easier and faster to use, but do not provide detailed scoring and in-depth feedback. It is more difficult to seek consistent scoring from independent assessors using holistic rubrics (Maki, 2010; Mearman, 2013; Oakleaf, 2009). The task and rubric for *Key Assessment 3* can be found in Appendix D.

3.5 Data Collection Procedures

Key Assessment 3 is one of six key assessments included in digital portfolios developed by all teachers completing *STM 506: STEM Practicum*. Following IRB compliance, the sample for this study gave consent for *Key Assessment 3* to be copied from their digital portfolios for review. The IRB approval letter is in Appendix G. All identifying information was removed from this key assessment prior to sharing this work with the independent assessors for this study.

Interrater Reliability

The task for *Key Assessment 3* specifically addresses a teacher's ability to plan instruction in reference to these four *Maryland State STEM SOP*:

- 1) SOP 2: integrates science, technology, engineering, and mathematics content;
- 2) SOP 4: engages students in inquiry;
- 3) SOP 6: requires students to collaborate as a STEM team; and
- 4) SOP 7: requires students to strategically apply technology to develop solutions to problems (McDaniel, 2015b).

Three independent assessors were selected with these standards in mind. They are experienced elementary and middle school classroom teachers and STEM education professional development providers. The three assessors have demonstrated strengths in developing STEM-centric lessons that integrate STEM content and practice, engage students in inquiry, require students to work collaboratively in STEM teams, and require students to apply technology in problem solving situations. For their role in this study, it was essential for the assessors to understand and be proficient in STEM-centric lesson design to assess the identified *Maryland State STEM SOP* within the teachers' planning.

Assessor One holds National Board certification and is an Elementary STEM Coach for a northwest North Carolina school division. For this position, she models best practice STEM lessons for elementary teachers and helps teachers plan and implement STEM-centric lessons. She has experience planning and implementing professional development experiences with

adults through her work as a science method adjunct instructor for a western North Carolina university and is a science instructor and curriculum developer for the national Mickelson ExxonMobil Teachers Academy.

Assessor Two is a Presidential Award-winning educator and the Senior STEM Educator at the National Institute of Aerospace. In this position, she develops design-based STEM curriculum for elementary, middle, and high school settings. Her work has been recognized by the National Science Teachers Association (NSTA) for modeling best practices in 21st Century pedagogy. She also designs and implements professional development experiences for pre-service and in-service teachers, focusing on developing an understanding of how engineering supports and strengthens standards-based curriculum to bring a real-world component to learning. As an active member of the Illinois Problem-Based Learning Network, this assessor brought an expertise in problem-based learning to her abilities to evaluate the teachers' key assessment responses.

Assessor Three has her Masters of Education in Curriculum and Instruction with a concentration in Science and Technology. She is the Science Education Manager for the Center for Inspired Teaching where she is working with Washington, DC public elementary teachers to create standards-based science curricula. She has been a professional development specialist for Discovery Education and a STEM coordinator. She was one of the 40 writers responsible for developing the *NGSS*. Her expertise in standards-based planning and inquiry instruction are strengths that she brought to her abilities to assess the teachers' responses to *Key Assessment 3*.

Training the Assessors

Research supports that training assessors reduces extreme assessor severity and leniency and improves interrater consistency (East, 2009; Yan, 2014). Rater training helps identify and

minimize rater bias through aligning raters' practical understanding of the rating scale and identified product elements (East, 2009; Yan, 2014). A three-hour training session prepared the assessors to consistently use *Key Assessment 3's* rubric to assess the teacher candidates' work.

Training materials for the session included: a training agenda (Appendix H), a copy of the *Maryland State STEM SOP* (Appendix A), *Key Assessment 3 Task and Rubric* (Appendix D), Assessors' Rubrics, and the *Key Assessment 3* artifacts for the sixteen participants. The candidates' responses to *Key Assessment 3* were pulled from their digital portfolios, per IRB requirement (Appendix G). The assessors were offered a choice in assessing the work electronically or using paper copies. Scoring materials were provided in both formats.

The training session framed the assessors' work within the requirements of earning the MSDE Instructional Leader: STEM (PreK-6) endorsement. Particular emphasis focused on the *Maryland State STEM SOP* and how these standards are assessed within the *Key Assessment 3* rubric. An explanation of the rubric, its component parts, and analysis of two practice artifacts were central to the training session (Oakleaf, 2009).

Maki's (2010) calibration process guided the approach to training the assessors to score submitted work. This norming process applies the scoring rubric to candidates' work to seek rater consistency. The assessors independently scored a candidate's sample. Then, together, they reviewed their responses to identify any patterns of consistent or inconsistent scoring. As a group, we discussed and reconciled any inconsistencies. The assessors were given a second sample and asked to score it independently. Once again, the group reviewed their responses as a team to look for patterns of scoring (Maki, 2010, p. 224). This exercise sought a common interpretation of the construct, in this situation the ability to plan STEM-centric lessons (Stemler, 2007). The team of assessors, with their similar experiences in STEM planning and teaching,

quickly aligned their calibration. The assessors were given one month from the date of the training to complete their scoring.

3.6 Data Analysis

The researcher used a variety of statistical methods, organized in Table 6, to analyze the data for this study.

Table 6
Research Questions, Data Collection, and Data Analysis

Research Questions	Data Sources	Method of Analysis	Data Collection
RQ#1: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>integrate science, technology, engineering, and mathematics disciplines?</i>	Key Assessment 3 – SOP2	Test of Hypothetical Value; Wilcoxon-signed-rank Test Interrater Reliability; Fleiss’ Kappa Statistic	September 2015
RQ#2: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>engage students in inquiry?</i>	Key Assessment 3 – SOP4	Test of Hypothetical Value; Wilcoxon-signed-rank Test Interrater Reliability; Fleiss’ Kappa Statistic	September 2015
RQ#3: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>support student collaboration as a STEM team?</i>	Key Assessment 3 – SOP6	Test of Hypothetical Value; Wilcoxon-signed-rank Test Interrater Reliability; Fleiss’ Kappa Statistic	September 2015
RQ#4: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>support students’ strategic application of technology?</i>	Key Assessment 3 – SOP7	Test of Hypothetical Value; Wilcoxon-signed-rank Test Interrater Reliability; Fleiss’ Kappa Statistic	September 2015

Wilcoxon-signed-rank Test

The rubric for *Key Assessment 3* is in Appendix D and has thirteen specific indicators assessed within four categories: exemplary, proficient, developing, and unsatisfactory. For this study, each category was tabulated numerically: exemplary (4), proficient (3), developing (2),

and unsatisfactory (1). Based on this calibration, the hypothetical of ≥ 3 test addressed the four research questions to consider to what extent the teachers demonstrate proficient or better (exemplary) abilities when designing lessons that: (1) integrate science, technology, engineering, and mathematics disciplines; (2) engage students in inquiry; (3) support student collaboration as a STEM team; and (4) support students' strategic application of technology. Nine of the thirteen indicators were used to address the research questions.

The Wilcoxon-signed-rank Test was used to assess the hypothetical ≥ 3 value for rubric scores. This nonparametric statistical hypothesis test is used with one-sample location studies and uses parametric data from probability distribution to make inferences about the targeted parameters (Rey & Neuhauser, 2008). As with many nonparametric tests, the Wilcoxon-signed-rank Test is based on rank order and inferentially tests whether the sum of the ranks is likely to be obtained by chance (Pratt, 2010). The Wilcoxon-signed-rank Test is used as a nonparametric alternative to the independent t-test in cases where populations may not be normally distributed and the sample sizes are small (Pratt, 2010). The test statistic for the Wilcoxon-signed-rank Test was compared to the designated critical value table based on the sample size of the participants. The critical alpha value was set at a significance level of $p \leq .05$.

Interrater Reliability and Fleiss' Kappa Statistic

Interrater reliability describes the level of agreement between or among two or more assessors using a particular instrument to assess a particular product at a set time (Mazurek, 2010; Stemler, 2004). The level of agreement is a statistical estimate of whether or not the assessors are using the rating tool without measurement error and in a predictable and reliable way. Stemler (2004) breaks interrater reliability into three categories: consensus estimates, consistent estimates, and measurement estimates. Consensus estimates consider the level at

which raters assign the same scores. This level of agreement assumes that it is reasonable to expect exact agreement from raters as they apply a scoring rubric to assess a product.

Consistency estimates look for patterns between raters analyzing the distribution of scores (Mazurek, 2010; Stemler, 2004). It is not expected that raters score products exactly the same for consistency estimates. Instead, the assessors are expected to consistently use the rubric following their own understanding of the tool, whether or not this aligns with other assessors' assessments. Estimates of measurement consider the raters' actual scores and may not result in consensus or consistency (East, 2009; Oakleaf, 2009; Stemler, 2004, 2007; Yan, 2014).

This study used consensus estimates for interrater reliability. Consensus estimates was chosen because the data are nominal and the rating scale represents qualitatively varying components (Stemler, 2004). The literature describes several statistics for consideration for interrater reliability: Pearson's product-moment correlation, Interclass Correlations, Kendall's coefficient, Spearman's rank coefficient, and Cohen's kappa statistic (Cohen, 1960; Conger, 1980; East, 2009; Mearman, 2013; Stemler, 2004; Stemler, 2007). For consensus estimates using nominal data, the literature overwhelmingly suggests using Cohen's kappa statistic (Cohen, 1960; Conger, 1980; Landis & Koch, 1977; Mearman, 2013; Stemler, 2004). Cohen's kappa estimates the degree of consensus between raters on nominal data after chance agreement is removed from consideration (Oakleaf, 2009; Stemler, 2004). While originally developed to measure agreement between two raters, Light and Fleiss have generalized Cohen's kappa for use with multiple raters (Fleiss, 1971; Light, 1971). For this study, Fleiss' kappa statistic was used to assess interrater reliability.

Fleiss' kappa statistic is expressed as a coefficient with a value from -1.00 to +1.0, with a score of 0 representing agreement that would occur by chance. The closer the value to +1.00, the

more consistent or reliable the ratings (Cohen, 1960; Fleiss, 1971; Mazurek, 2010). For this study, interrater consensus agreement ≥ 0.90 among the assessors was set.

Most of the literature points to an interpretation of kappa values defined by Landis and Koch, citing Landis and Koch's table delineating the strength of agreement outlined in Table 7 (Lance, Butts, & Michel, 2006; Landis & Koch, 1977; LeBreton & Senter, 2008; Stemler, 2004).

Table 7

Interpretation of Kappa Values (Landis & Koch, 1977, p. 165)

<u>kappa</u>	<u>Strength of Agreement</u>
<0.00	Poor
0.000 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost Perfect

3.7 Researcher Stance

The researcher is employed by the NIA and has a longstanding relationship with McDaniel College and CCPS. Her undergraduate and master's degree are from McDaniel College, and she completed her K-12 education and started her teaching career in CCPS. McDaniel College and CCPS turned to NIA to seek the researcher's expertise in developing and teaching courses within McDaniel College's ESIL program.

Between the summer of 2012 and 2015, the researcher developed and taught the first five McDaniel College ESIL courses: STM 501, STM 502, STM 503, STM 504, and STM 505. She based the design of these courses on research cited within this study, developing the McDaniel College ESIL model as the framework for planning, implementation, and evaluation of the ESIL graduate coursework. A second cohort of CCPS teachers began the ESIL series the summer of 2013; a third cohort started the series the summer of 2014; and a fourth cohort began the series the summer of 2015. The researcher has been the primary instructor for the five courses for each

cohort. She is currently mentoring several teachers within the first cohort, helping them transition from participant to adjunct faculty in preparation to teach future ESIL courses. Mentoring prospective instructors is part of her role as the Elementary STEM Coordinator for McDaniel College, a position created by the college the summer of 2015.

The development and implementation of the final ESIL course, *STM 506: STEM Education Practicum*, was led by Cindy Eckenrode, retired CCPS elementary science supervisor and McDaniel College instructor for the elementary science methods undergraduate course. Ms. Eckenrode guided the first cohort through the completion of the required MSDE key assessments, culminating in supporting the teachers through the development of their digital portfolio. One of the six key assessments, *Key Assessment 3, Competence in Planning*, assesses the teachers' skills in planning STEM-centric lessons. Planning lessons that incorporate *Maryland's State STEM SOP* through critical thinking, problem solving, and collaboration is an essential component of coursework leading to the MSDE Instructional Leader: STEM (Pre-K) endorsement (MSDE, 2013). *Key Assessment 3* was the source of data utilized within this study.

The researcher acknowledges that she has a vested interest in this study from many perspectives. She designed the ESIL courses to focus on developing the participants' abilities to plan STEM-centric lessons. This study gathers data impacted by the researchers' involvement in the design and teaching of the ESIL courses.

As the McDaniel College Elementary STEM Coordinator, the investigator will be recruiting other Maryland counties to participate in the ESIL program. The success of the CCPS cohort of teachers could influence other counties' interest in McDaniel College's ESIL program. From the lenses of course developer, instructor, and program coordinator, the researcher is

interested in gathering data about participating teachers' proficiency in planning STEM-centric lessons that supports or identifies areas of weakness for improvement within the ESIL program.

With this in mind, the investigator designed this study to assure a fair and unbiased assessment of the first cohort's abilities to plan STEM-centric lessons. The lessons and reflections submitted as artifacts for *Key Assessment 3* were evaluated by a panel of three, independent elementary STEM education experts. The assessors received training as a team to use the state-approved rubric to review the artifacts. Training built a common understanding of the *Maryland State STEM SOP*, as they were integrated into the approved rubric, and guided the assessors through the use of the rubric to seek consensus. The use of outside assessors distanced the researcher from gathering data, herself, from the sample population.

Designing this study to be a quantitative study was another measure the researcher has taken to avoid bias within the findings. Data collected by the assessors was analyzed for interrater reliability using Fleiss' kappa statistic and as nonparametric data to assess the hypothetical ≥ 3 value of the rubric scores. Following data analysis, the researcher asked the assessors to review the findings as a member check.

The methodology was proposed to avoid researcher bias and assure that appropriate measures were taken to avoid personal bias in the gathering and analysis of data. The findings will be used to reinforce and/or improve McDaniel College's ESIL coursework, as well as other professional development experiences designed to prepare elementary educators to plan STEM-centric lessons.

3.8 Summary

This study investigated the ability of a group of elementary teachers, who had completed the McDaniel College ESIL graduate program, to proficiently plan lessons that integrate science,

technology, engineering, and mathematics disciplines; engage students in inquiry; support student collaboration as a STEM team; and support students' strategic application of technology. As evidence for the teachers' proficiency in planning STEM-centric lessons, a state-approved analytic rubric for *Key Assessment 3: Competence in Planning* was used to assess the sixteen teachers' lessons and reflections. Three STEM education experts, following rater training, independently scored the sample's assessments. Fleiss' kappa statistic was used to assess interrater agreement. The test of hypothetical value, using the Wilcoxon-signed-rank Test, was used to support whether or not the teachers' demonstrate proficient abilities in four areas of STEM-centric lesson design.

Chapter 3 detailed the methodology used for this study, outlining the research hypotheses and describing the research design. Additionally, this chapter described the task and rubric, as well as the sixteen teachers who completed this task. The chapter concluded with details about data collection, including how assessors were selected and trained to assure rater consistency during their review of the assessment. Statistical data analysis was described. Chapter 4 presents the findings of the collected data from the study.

CHAPTER 4: RESULTS

4.1 Purpose of the Study

The purpose of this study was to determine the ability of a group of elementary teachers to proficiently plan lessons that integrate science, technology, engineering and mathematics disciplines, engage students in inquiry, support student collaboration as a STEM team, and support students' strategic application of technology. This study also examined the interrater reliability of three independent assessors who reviewed the teachers' lessons using an MSDE state-approved rubric. The sample for this study was sixteen CCPS teachers within the pilot cohort of teachers completing the McDaniel College ESIL program. This chapter includes a description of the participants within this study, instrumentation of the study, data assessment, data analysis, and a summary.

4.2 Participants in the Study

The sixteen participants in this study were members of the first cohort of CCPS teachers to complete the required eighteen hours of McDaniel College ESIL graduate coursework and six key assessments to earn the MSDE Instructional Leader: STEM (PreK-6) endorsement. In addition to maintaining a 3.0 GPA in the graduate coursework, candidates must earn a proficient or exemplary rating on each of the key assessments to earn the MSDE endorsement.

Participants were asked to self-report demographics and their educational background and professional experiences within their STEM education practicum. They identified their current teaching assignment, their years in the teaching profession in 5-year experience intervals, and level of postsecondary degrees. Additionally, participants were asked to identify specific undergraduate and graduate degrees attained and educational leadership roles and merit-based professional development experiences.

This sample included first through fifth grade teachers, resource teachers such as math and literacy coaches, and one administrator (a math resource teacher who accepted an administrative position during the ESIL program). Fifteen of the sixteen teachers were female and all of the teachers had at least 6 years of experience as educators. Approximately 70% had between 6 and 15 years of experience. Twenty-five percent of the participants had between 16 and 25 years of experience and one participant has been teaching more than 25 years.

As would be expected, all of the participants held an undergraduate degree and the majority of the group, thirteen of the sixteen (81.25%), held an undergraduate degree in elementary education. The other three participants each held a different undergraduate degree; one (6.25%) in Liberal Arts and Technology; one (6.25%) in Business Management and Finance; and one (6.25%) in Mass Communication and Spanish.

The three teachers holding undergraduate degrees that were not in elementary education held graduate degrees that included K-6 endorsement. Overall, eighty-one percent of the group had graduate degrees, with the majority (46.15%) in Curriculum and Instruction. Three participants (23.08%) held graduate degrees in Math Instructional Leadership and two of the participants (15.38%) earned their graduate degree in Elementary Education. The last two participants with graduate degrees held two different degrees; one (7.70%) in Educational Technology and the other (7.70%) in Special Education.

The teachers within this study also held a variety of leadership roles. Ten of the sixteen (62.5%) had served on curriculum writing teams and six (37.5%) had been part of their school's school improvement team. Five of the sixteen (31.25%) had served as grade-level team leaders, while five (31.25%) had chaired school-based committees. Three of the sixteen (18.75%) had been selected for merit-based professional development experiences; specifically two (12.5%)

attended the MSDE STEM Educator Effectiveness Academy and one (6.25%) attended the national Mickelson ExxonMobil Teachers Academy. Two (12.5%) participants held leadership roles in their school’s parent-teacher association and one (6.25%) participant was a mentor teacher. Table 8 delineates the demographics for this study’s sample population.

Table 8
Sample Population Demographics, Educational Background, and Professional Experience

	Count	Percentage
Gender		
Male	1	6.25%
Female	15	93.75%
Years Working as an Educator		
1-5 years	0	0%
6 – 10 years	5	31.25%
11 – 15 years	6	37.5%
16 – 20 years	2	12.5%
20-25 years	2	12.5%
>25 years	1	6.25%
Current Assignments		
First Grade Teacher	1	6.25%
Second Grade Teacher	2	12.5%
Third Grade Teacher	2	12.5%
Fourth Grade Teacher	1	6.25%
Fifth Grade Teacher	6	37.5%
Resource Teacher (Math coach and Title I)	3	18.75%
Administrator (Assistant principal)	1	6.25%
Degrees		
Undergraduate Degrees Only	3	18.75%
Undergraduate and Graduate Degrees	13	81.25%

Collectively, the elementary teachers involved in this study were an accomplished cohort of experienced educators who demonstrated school-based leadership and a dedication to continuous educational improvement with initial or current assignments in grade 1-5 classrooms.

4.3 Instrumentation

Key Assessment 3: Assessment of Competence in Planning is one of the six key assessments required to earn the MSDE endorsement for Instructional Leader: STEM (PreK-6). Two artifacts are submitted for this key assessment: a coded lesson as evidence that the lesson

incorporates four *Maryland State STEM SOP* targeting the integration of science, technology, engineering and mathematics disciplines (*SOP2*), engaging students in inquiry (*SOP4*), supporting student collaboration as a STEM team (*SOP6*), and supporting students’ strategic application of technology (*SOP7*); and a teacher reflection expounding on the lesson design to promote student practice of the required *SOP*.

A state-approved, full-model, analytic rubric was used to score *Key Assessment 3*’s artifacts. The rubric scores the teachers’ as exemplary, proficient, developing, and unsatisfactory. Each rating is tabulated numerically: exemplary (4), proficient (3), developing (2), and unsatisfactory (1). The rubric is broken into thirteen indicators, grouped within four assessment categories. Nine of the thirteen indicators provided data for this study’s four research questions. A summary of the indicators matched to the four research questions are organized within Table 9.

Table 9
Key Assessment 3 Indicators Matched with Research Questions

Research Question	Indicators from the rubric that match with the RQ
RQ#1: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>integrate science, technology, engineering, and mathematics disciplines?</i>	A2, C1, C2
RQ#2: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>engage students in inquiry?</i>	A1, A5
RQ#3: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>support student collaboration as a STEM team?</i>	A3
RQ#4: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>support students’ strategic application of technology?</i>	A4, B1, B2

The full task and rubric for *Key Assessment 3* can be found in Appendix D. The table outlining the full text of the indicators can be found in Appendix I. The four research questions for this study sought evidence for the teachers' proficient planning abilities in reference to the four identified *SOP*.

Three independent assessors with experience in developing STEM-centric lessons used the state-approved rubric to review the sixteen sample teachers' *Key Assessment 3* artifacts. Prior to their review of the artifacts, the researcher trained the assessors following Maki's (2010) calibration process to improve interrater consistency. A password protected web-based organizational tool, LiveBinder, was used for this training session. A screenshot of this tool can be found in Appendix J. The training agenda, a copy of *Maryland's State STEM SOP*, *Key Assessment 3 Task and Rubric*, Assessors' Rubrics, and the *Key Assessment 3* artifacts for the sixteen participants were organized within the LiveBinder. These resources can be found as appendices: training agenda (Appendix H), *Maryland State STEM SOP* (Appendix C), and *Key Assessment 3 Task and Rubric* (Appendix D). The Assessors' Rubrics were copies of the *Key Assessment 3 Rubric* in a format that could be scored electronically for ease of assessment. The assessors completed the review of all sixteen teacher artifacts approximately one month from the date of the training. An example of one set of artifacts can be found in Appendices K and L.

4.4 Data Assessment

Training the Assessors

Maki's calibration process framed the researcher's three-hour training session with the three independent assessors (Maki, 2010). Two of the assessors joined the researcher for face-to-face training; the third assessor joined the group virtually by conference phone. After reviewing the *Maryland State STEM SOP*, the researcher and assessors analyzed the essential components

of the task for *Key Assessment 3*. To seek a clear and consistent understanding of the targeted construct, the researcher and assessors analyzed each of the descriptive indicators on the *Key Assessment 3* rubric. The assessors then independently scored both components of one participant's submitted artifact: a coded lesson paired with the participant's written reflection of the coded elements within the lesson. Following their independent scoring of the first artifact, the assessors shared their responses to identify patterns of consistent or inconsistent scoring. The assessors' scores aligned at proficient or exemplary (≥ 3) for eight of the nine indicators matched with the research questions. The group discussed their interpretations of the misaligned indicator and verified their scores based upon evidence within the coded lesson. These discussions enabled the group to clarify their understanding of the misaligned indicator and reconcile any differences.

A second participant's artifact was scored independently by the three assessors. Once again, following their independent scoring, the assessors reviewed their responses as a team. The individual assessments again demonstrated consensus for eight of the nine indicators. The team reviewed their discrepancy and discussed the language of the rubric to seek common understanding. Following these two calibration exercises, the assessors indicated that they held a common interpretation of the construct, were confident in their understanding of the task and prepared to independently review the remaining 14 paired artifacts. The three assessors completed their review of the participants' artifacts approximately one month from the date of the training session. In concluding the review of the artifacts, the combined results and analysis of data were shared with the team of assessors.

Interrater Reliability and Fleiss' Kappa Statistic

The assessors' scores for each participant's submitted artifacts were organized into a matrix to determine interrater reliability using Fleiss' kappa statistic. Fleiss' kappa is a generalization of Cohen's kappa (Fleiss, 1971). Cohen's kappa statistic estimates the degree of consensus between two raters on nominal data (Oakleaf, 2009; Stemler, 2004). Fleiss' kappa is used with studies involving multiple observers and multiple categories (Fleiss, 1971; Light, 1971).

The researcher organized data into categories and indicators within a matrix to determine the Fleiss' kappa statistic. Two categories represented the assessors' scores indicating proficient or exemplary (≥ 3) planning and unsatisfactory or developing (< 3) planning. Nine indicators for each of the sixteen teachers in the study resulted in a total of 144 indicators ($n=144$). Each cell within the matrix was filled with the number of raters who agreed that a certain indicator matched a particular category. A rater agreement of ≥ 0.90 was set and met for the three assessors. The average proportion of rater agreement (\bar{P}) was 0.91. Proportion expected by chance (P_e) was 0.86. The kappa score was 0.34. A summary of this data is in Table 10.

Table 10
Fleiss' Kappa Summary

N=144	
\bar{P}	0.91
P_e	0.86
kappa	0.34

Wilcoxon-signed-rank Test and Test of Hypothetical Value

The assessors evaluated *Key Assessment 3* artifacts to determine to what extent the teachers in this study proficiently developed lessons that: 1) integrate science, technology,

engineering, and mathematics disciplines; 2) engage students in inquiry; 3) support student collaboration as a STEM team; and 4) support students’ strategic application of technology.

These four attributes of the submitted lesson artifacts correspond to the four research questions.

Scores for each participant’s submitted artifact were organized by corresponding research question. As identified in Table 9, rubric indicators A2, C1, and C2 provided data for RQ#1. Indicators A1 and A5 provided data for RQ#2. Indicator A3 provided data for RQ#3. Indicators A4, B1, and B2 provided data for RQ#4. To calculate the Wilcoxon-signed-rank Test, data was organized into a table with four columns categorizing each research question and sixteen rows, one for each participant.

The Wilcoxon-signed-rank Test was used to assess the hypothetical value ≥ 3 for the assessors’ scores. The stated hypotheses for each research question were examined to determine proficiency (≥ 3) in the four STEM standards of practice exhibited through the teacher artifacts.

The test statistic for the Wilcoxon-signed-rank Test was compared to the designated critical value table based on the sample size of the participants through a normative approximated method. The critical alpha value was set at a significance level of $p \leq .05$. A summary of this data is in Table 11.

Table 11
Wilcoxon-signed-rank Test for the Test of Hypothetical Value

Research Hypothesis	n	Median Est.	Wilcoxon Stat.	p-value	Method
RQ1-H ₁	16	3	120	0.9923	Norm. Approx.
RQ2- H ₁	16	3.5	135	0.9995	Norm. Approx.
RQ3- H ₁	16	3	80	0.4512	Norm. Approx.
RQ4- H ₁	16	3.5	131	0.9988	Norm. Approx.

4.5 Data Analysis

Interrater Reliability and Fleiss' Kappa Statistic

The Fleiss' kappa statistic estimates the degree of consensus among more than two raters on nominal data after chance agreement is removed from consideration (Fleiss, 1971; Oakleaf, 2009; Stemler, 2004). Analysis of the data indicated a 0.91 average proportion of agreement among the three assessors in their reviews of the participants' abilities to plan lessons that addressed identified *SOP* at a level of proficient (3) or better (4). A 0.86 random chance proportion of agreement was possible. The kappa score, 0.34, falls within the acceptable range on Landis and Koch's Table of Interpretation for Kappa Values. This level of agreement indicated interrater reliability regarding the assessors' reviews of *Key Assessment 3's* artifacts. A summary of this data was seen in Table 10.

Wilcoxon-signed-rank Test and Test of Hypothetical Value

The test of hypothetical value was used to address the four research hypotheses and determine whether or not the teachers demonstrated proficient abilities in planning the four specific components of STEM-centric lessons. Proficient or exemplary planning abilities were identified by the assessors' scores of 3 (proficient) or 4 (exemplary) on the required rubric. Specific indicators within the rubric were matched with each of the four research hypotheses, as summarized in Table 9.

The Wilcoxon-signed-rank Test was used to analyze the scored rubrics for each teacher within the sample to complete the test of hypothetical ≥ 3 value. The Wilcoxon-signed-rank Test is a nonparametric procedure used to analyze a study hypothesis involving a single sample to determine whether the sample is derived from a population with a median value other than Θ , the value set by the researcher (Rey & Neuhauser, 2008; Sheskin, 2000). The Wilcoxon-signed-rank

Test ranks the calculated differences between each participant's score and the hypothesized value of the population median. By focusing on ranks, this test allows researchers to focus on the ordinal relationship among the measures, specifically addressing the determined hypothetical value (Sheskin, 2000). The research hypotheses for this study set the median for this test at ≥ 3 . If the calculated proportional value for the test is determined to be *greater than* the corresponding critical value, the researcher could conclude that there was a high likelihood that the sample was derived from a population with the median value ≥ 3 , resulting in failing to reject the stated test hypothesis, $\Theta \geq 3$. If the calculated proportional value for the test is determined to be less than the corresponding critical value, the researcher could conclude that the sample was from a population with the median value < 3 , resulting in rejecting the test hypothesis, $\Theta \geq 3$. The results of the data analysis for each of the four research hypotheses were displayed in Table 11 and are discussed below.

Research Hypotheses

All four research hypotheses were directional hypotheses described by the notation $H_{1: \Theta} \geq 3$. For this study, the Wilcoxon-signed-rank Test was used to analyze the three independent assessors' scoring of the teachers' submitted artifacts for *Key Assessment 3*, focusing on attributes of the teachers' planning as identified by four *Maryland State STEM SOP*. Each research hypothesis targeted one of the specified *SOP*. The Wilcoxon T statistic was computed by comparing the obtained value of T to a *Table of Critical T Values for the Wilcoxon-signed-rank Test* (Sheskin, 2000). To evaluate the stated hypothesis, the obtained value of T must be equal to or less than the tabled critical T value at the alpha value of $p \leq .05$. There was no assumption of normality, due to the sampling method of the specified population and their completed treatment protocol, therefore a nonparametric alternative was deemed appropriate.

The teachers included in this study were members of the McDaniel College pilot cohort and had completed the McDaniel ESIL graduate program.

Hypothesis 1

RQ1 - H₁: Teachers within the McDaniel College pilot cohort are proficient or exemplary in developing lessons that integrate science, technology, engineering, and mathematics disciplines.

Research question 1's directional hypothesis described a circumstance where $H_1: \theta \geq 3$. Using the Wilcoxon-signed-rank Test, the median value for the data for this research hypothesis was 3, falling within the $H_1: \theta \geq 3$. The Wilcoxon T statistic for this analysis was 120. The corresponding critical p-value (0.99) resulted in the researcher failing to reject RQ1 - H₁.

With respect to whether the McDaniel College pilot cohort teachers are proficient or exemplary in developing lessons that integrate science, technology, engineering, and mathematics, the researcher concluded that the analysis of the data supported that the sample of sixteen subjects comes from a population with a median score of 3 or greater. Based on the study instrumentation and definitions, the median value of 3 indicated proficiency in planning lessons that integrate science, technology, engineering, and mathematics disciplines.

Three indicators within the rubric matched with RQ1. The assessors noted examples of developing (2), proficient (3), and exemplary (4) planning for this research hypothesis within the reviewed artifacts. Developing ability for this construct was described as designing a learning experience that: (1) “develops content knowledge without meaningful integration and where practices of the discipline are limited; (2) has limited opportunities for students to demonstrate their understanding of STEM content and where opportunities rely heavily on the recall of information with very little application of concepts; and (3) using STEM notebooks as a tool for

students to record their observations and material that the teacher deems important” (McDaniel, 2012b). Proficient ability of this construct was described as developing learning experiences that: (1) “are guided by the teacher where disciplinary content knowledge and practices are integrated; (2) offer students multiple opportunities to demonstrate their understanding of the STEM content by recalling and applying concepts; and (3) where STEM notebooks are used purposefully to permit students to demonstrate an accurate understanding of STEM content” (McDaniel, 2015b). Exemplary ability for this research hypothesis was described as developing learning experiences: (1) “that are driven by students making connections between disciplinary content knowledge and practices; (2) that are designed to offer students multiple opportunities to demonstrate their understanding of the STEM content by recalling and applying concepts and providing them an opportunity to discuss how their learning evolved; and (3) where STEM notebooks are used to inculcate habits of mind that permit students to demonstrate a comprehensive understanding of STEM content through evidence-based arguments” (McDaniel, 2012b). The results supported that the assessors consistently noted that the participants’ lessons reflected proficient planning as described by the specific descriptions within the instrumentation.

Hypothesis 2

RQ2 – H₁: Teachers within the McDaniel College pilot cohort are proficient or exemplary in developing lessons that engage students in inquiry?

Research question 2’s directional hypothesis described a circumstance where $H_1: \theta \geq 3$. Using the Wilcoxon-signed-rank Test, the median value for the data for this research hypothesis was 3.5, falling within the $H_1: \theta \geq 3$. The Wilcoxon T statistic for this analysis was 135. The corresponding critical p-value (0.99) resulted in the researcher failing to reject RQ2 - H₁.

With respect to whether the McDaniel College pilot cohort teachers are proficient or exemplary in developing lessons that engage students in inquiry, the researcher concluded that the analysis of the data supported that the sample of sixteen subjects comes from a population with a median score of 3 or greater. Based upon the study instrumentation and definitions, the median value of 3.5 indicated proficiency in planning lessons that engage students in inquiry.

Two indicators within the rubric matched with RQ2. The assessors noted examples of developing (2), proficient (3), and exemplary (4) planning for this research hypothesis. Developing ability for this construct was described as designing a lesson that: (1) “includes teacher directed experiences in which content standards are developed with some student involvement: and (2) describes learning experiences where the teacher models the use of the practices of the STEM disciplines, but provides limited opportunities for students to use the practices themselves” (McDaniel, 2012b). Proficient ability of this construct was described as developing a lesson plan that includes learning experiences: (1) “in which content standards are developed to help students make connections between content and a complex question, global issue, and/or real world challenge; and (2) which lead students to use the practices of the STEM disciplines, such as asking questions, defining problems, using models, and carrying out investigations” (McDaniel, 2015b). Exemplary ability for this research hypothesis was described as developing a lesson plan that includes opportunities: (1) “for students to engage in the inquiry necessary to answer their own questions about complex questions, global issues, and/or real world challenges; and (2) for students to develop science and engineering practices as they seek answers to thoughtful questions they have developed, define complex problems, develop and use models, and plan and carry out investigations” (McDaniel, 2015b). The results of this study

support that the assessors consistently noted proficient abilities in the participants' planning to engage students in inquiry as described by the specific descriptions within the instrumentation.

Hypothesis 3

RQ3 – H1: Teachers within the McDaniel College pilot cohort are proficient or exemplary in developing lessons that support student collaboration as a STEM team.

Research question 3's directional hypothesis described a circumstance where $H_1: \theta \geq 3$. Using the Wilcoxon-signed-rank Test, the median value for the data for this research hypothesis was 3, falling within the $H_1: \theta \geq 3$. The Wilcoxon T statistic for this analysis was 80. The corresponding critical p-value (0.45) resulted in the researcher failing to reject RQ3 - H1.

With respect to whether the McDaniel College pilot cohort teachers are proficient or exemplary in developing lessons that support student collaboration as a STEM team, the researcher concluded that the analysis of the data supported that the sample of sixteen subjects comes from a population with a median score of 3 or greater. Based on the study instrumentation and definitions, the median value of 3 indicated proficiency in planning lessons that support student collaboration as a STEM team.

One indicator within the rubric matched with RQ3. The assessors noted examples of developing (2), proficient (3), and exemplary (4) planning for this research hypothesis. Developing ability for this construct was described as designing a lesson plan that “suggests that students work in collaborative teams, but does not clearly define expectations” (McDaniel, 2015b). Proficient ability of this construct was described as developing a lesson plan that (1) “describes how students work in formally structured teams with clearly defined expectations for individual and team accountability” (McDaniel, 2015b). Exemplary ability for this research hypothesis: (1) “suggests how students work in formally structured teams with clearly defined

expectations for individual and team accountability, but allows for students to take ownership in how their work is planned and structured; and (2) creates a learning experience where the collaborative group functions in a similar manner to a real-world collaborative team” (McDaniel, 2015b). The results supported that the assessors consistently noted that the participants’ lessons reflected proficient planning as described by the specific descriptions within the instrumentation.

Hypothesis 4

RQ4 – H1: Teachers within the McDaniel College pilot are proficient or exemplary in developing lessons that support students’ strategic application of technology.

Research question 4’s directional hypothesis described a situation where $H_1: \theta \geq 3$.

Using the Wilcoxon-signed-rank Test, the median value for the data for this research hypothesis was 3.5, falling within the $H_1: \theta \geq 3$. The Wilcoxon T statistic for this analysis was 131. The corresponding critical p-value (0.99) resulted in the researcher failing to reject RQ4 - H1.

With respect to whether the McDaniel College pilot cohort teachers are proficient or exemplary in developing lessons that support students’ strategic application of technology, the researcher concluded that the data supported that the sample of sixteen subjects comes from a population with a median score of 3 or greater. Based upon the study instrumentation and definitions, the median value of 3.5 indicates proficiency in planning lessons that support student’s strategic application of technology.

Three indicators within the rubric matched with RQ4. The assessors noted examples of developing (2), proficient (3), and exemplary (4) planning for this research hypothesis.

Developing ability for this construct was described as designing a lesson plan that describes learning experiences where: (1) “only the teacher uses technology tools; (2) the teacher explains to the students the limits, risks, and impacts of technology; and (3) the teacher suggests how to

create a new technology to extend human capability” (McDaniel, 2015b). Proficient ability of this construct was described as developing a lesson plan that includes learning experiences where students: (1) “use technology tools to help them develop solutions to problems and/or construct answers to complex questions; (2) are asked to consider the limits, risks, and impacts of technology; and (3) are asked to imagine/plan a new technology to extend human capability” (McDaniel, 2015b). Exemplary ability for this research hypothesis was described as developing a lesson plan where students: (1) “select technology tools and use them creatively to develop solutions to problems and/or construct answers to complex questions; (2) are asked to systematically analyze the limits, risks, and impacts of technology and to defend their findings; and (3) are asked to improve or create a new technology to extend human capability” (McDaniel, 2015b). The results of this study support that the assessors consistently noted proficient abilities in the participants’ planning to engage students in inquiry as described by the specific descriptions within the instrumentation.

4.6 Summary

This chapter described the purpose and design of this study as it related to the data and analyses. The participants of this study were also described with summaries of demographic data and descriptions of educational background and professional experiences. In the instrumentation section, the assessment rubric and rubric indicators were described pertaining to matching with the study’s four research questions. The data assessment section described the training session for the independent assessors and outlined the organization of the data in preparation for calculating the Fleiss’ kappa statistic and conducting the Wilcoxon-signed-rank Test. Fleiss’ kappa statistic results were discussed as indicators to measure the interrater reliability of the three independent assessors. A 0.91 proportion of agreement consensus was

documented among the three assessors. The results of the Wilcoxon-signed-rank Test were evaluated for each research study hypothesis. These results led to the researcher to fail to reject all four research hypotheses suggesting proficient planning abilities for the targeted *Maryland State STEM SOP* for the sample population. Chapter 5 summarizes this study, discusses the results of this study, and presents the implications, suggestions for further studies and conclusions from the data analysis of the Wilcoxon-signed-rank Test and Fleiss' kappa statistic.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

5.1 Introduction

The purpose of this study was to explore the McDaniel College ESIL pilot cohort's ability to proficiently plan lessons that incorporated the *Maryland State STEM SOP* targeting integration of STEM content, inquiry learning, students' abilities to collaborate as a STEM team and students' strategic application of technology. Data collection, in the form of reviewing and scoring study participants' lesson plans and self-reflections, was completed by three independent assessors. Additionally, the researcher examined the interrater reliability among the three assessors. This chapter summarizes the study and offers discussion and conclusions about study results. Limitations of the study's results, implications for preparing elementary in-service teachers to plan lessons that incorporate key *Maryland State STEM SOP*, and suggestions for further research are also presented in this chapter.

5.2 Summary of the Study

The goal of this study was to add to the field's knowledge of elements for inclusion in graduate coursework that lead to elementary in-service teachers' proficiency in planning STEM-centric lessons by examining the planning abilities of a group of elementary teachers upon the completion of their McDaniel College ESIL graduate coursework. All sixteen teachers from the pilot cohort who completed the six McDaniel ESIL courses and earned the MSDE Instructional Leader: STEM (PreK-6) endorsement were invited and chose to participate in this study.

Participants' lesson plans and self-reflections, coded and written for *Key Assessment 3: Competence in Planning*, were used to assess the teachers' planning abilities. Prior to this study, these artifacts were included in each participant's digital portfolio, a requirement for the

Instructional Leader: STEM (PreK-6) endorsement. Participants offered the researcher access to this work for the purpose of this study.

The researcher identified and selected three STEM education experts, based upon set criteria, to review the participants' artifacts. Following rater training conducted by the researcher, the independent assessors reviewed the participants' artifacts using a state-approved rubric for this task. The methods of analysis used in this study included a test of hypothetical value, conducted using the nonparametric Wilcoxon-signed-rank Test, and assessor interrater reliability, assessed using Fleiss' kappa statistic.

5.3 Discussion of Results

Sample Population

The sample population was an accomplished group of educators invited by their administration and CCPS central office to join the McDaniel ESIL pilot cohort. More than 80% of the sample already had or earned graduate degrees during the two and a half years dedicated to completing the ESIL coursework and earning the MSDE Instructional Leader endorsement. The majority of the teachers (67.75%) had between 6 – 16 years of teaching experience. Many held leadership roles, including serving on curriculum writing and school improvement teams, leading their grade-level, and chairing school-based committees. This group was reflective of prior studies that indicated that teachers' experiences and content knowledge might impact their planning abilities (Borko & Niles, 1987; Wing-mui So, 1997). Prior studies also reflected that elementary teachers who pursue professional growth experiences through advanced coursework often have diverse experiences and involvement in professional committees (Burger, 1988).

Interrater Reliability and Research Hypotheses

A 0.91 average proportion of agreement indicated a strong rater reliability regarding the assessors' reviews of the participants' coded lessons. The three assessors are experienced elementary and middle school classroom teachers and are nationally recognized as exemplary STEM education professional development providers. They have strengths in developing STEM-centric lessons that align with the attributes identified within the four *Maryland State STEM SOP* assessed in this study. The three assessors demonstrated their consistent approach to reviewing the participants' artifacts during two calibration exercises within the training session. It was not a surprise to find this level of consensus among the assessors, given their experiences and expertise.

With the strong interrater reliability, the results of each research hypothesis were approached with a level of confidence. All data analysis resulted in the researcher failing to reject all four research hypotheses. There was evidence to support that the sample group of teachers were proficient or exemplary in their planning of lessons that integrate science, technology, engineering, and mathematics disciplines, engage students in inquiry, support student collaboration as a STEM team, and support students' strategic application of technology.

McDaniel ESIL Program Design

The McDaniel College ESIL courses were intended to prepare elementary teachers to develop inquiry- and design-based 7E learning cycle constructivist lessons that addressed learning outcomes identified within *NGSS*, *STL*, and *Maryland's State STEM SOP*. Planning integrated STEM lessons that incorporated both inquiry and design-based learning, while addressing the *Maryland State STEM SOP*, was emphasized in four of the six courses: *STM 501*, *STM 502*, *STM 504*, and *STM 505* (McDaniel, 2015a). The results indicated that the teachers

within this study demonstrated consistent ability to proficiently plan lessons that incorporated the four targeted *Maryland State STEM SOP*.

By design, the McDaniel College ESIL coursework was developed to meet the needs of adult learners and incorporate best practice elements of planning, implementation, and evaluation of professional learning experiences. All of the courses are hybrid courses, a blend of online and face-to-face instruction (McDaniel, 2015a). Online, asynchronous discussions promoted teachers' self-reflection and analysis while supporting collaboration, shared resources, and networking (Almendarez-Cadena, 2014; Dede et al., 2009; Zepeda, 2015).

The cohort model built a supportive, critical mass of participants to impart learning throughout the CCPS school system (Haney & Lumpe, 1995; Zepeda, 2012). The 7E curricular model has been adopted by the CCPS specialists to frame curriculum design for the county. Lessons developed by the pilot cohort were reviewed and incorporated into the county's curriculum, modeling job-embedded instruction where assignments were practical and immediately applied within classroom settings (Darling-Hammond, 1997; Knowles et al., 1998; Zepeda, 2012). The coursework was paced to provide ongoing and sustained professional growth following a model of continuous improvement (Darling-Hammond et al., 2009; Learning Forward, 2015a; Sparks & Loucks-Horsley, 1989).

Key assessments served as capstone performance assessment tasks throughout the ESIL coursework, assessing the teachers' STEM content knowledge, planning abilities, abilities to assess student growth, and growth as STEM leaders (McDaniel, 2015a). *Key Assessment 3*, as seen in this study, specifically targeted the teachers' abilities to plan STEM-centric lessons and provided an opportunity for the teachers to improve lessons as a component of their reflection.

Findings from this study suggest that the design and instruction of the McDaniel ESIL coursework may have prepared elementary educators to proficiently plan STEM-centric lessons. These findings may help inform future professional development experiences for elementary educators in regard to planning STEM-centric lessons.

5.4 Limitations of Results

The sample size, as well as the characteristics of the group, may have been a limiting factor in this study. While a sample size of sixteen teachers is in line with the methods of analysis, a larger sample might yield a greater range of results. The study group was also a selected group of accomplished educators with a variety of higher education and school-based leadership experiences. The group's proficiencies cannot be attributed exclusively to the professional development coursework and the participants' work within the McDaniel ESIL cohort. The study sample had culminating abilities prior to and concurrent with the McDaniel ESIL experiences. Therefore, the researcher cannot pinpoint the exacting reason why these teachers have demonstrated proficiency. Their work within the ESIL program is a commonality and one piece of the equation, but not the full equation. A larger, more diverse, and less experienced sample may demonstrate more varied proficiencies than what was observed in this study. Inclusion of a pre-assessment, to document the study sample's prior proficiencies in planning, might help measure the participants' growth in planning ability due directly to ESIL coursework. Comparing the teachers' submitted coded lessons from *Key Assessment 3* with a lesson each had developed prior to ESIL coursework, would provide a baseline for the teachers' planning abilities for comparison.

The study group's proficiencies are evident, based upon the specific instrumentation, and may not be generalized to the teachers' abilities for proficient STEM-centric planning in

reference to other metrics. The assessed artifacts were evidence of proficiency as described by specific indicators within *Key Assessment 3*'s rubric. Three indicators from the rubric provided evidence for RQ#1 (A2, C1, C2) and RQ#4 (A4, B1, B2); two indicators provided evidence for RQ#2 (A1, A5). Only one indicator on the assessment rubric matched with RQ#3 (A3). While the data and findings led to the researcher failing to reject the RQ#3 research hypothesis, the p-value (0.45) for this research hypothesis was noticeably less than the p-values for the other three research hypotheses (0.99). This may be due to less evidence to assess this construct.

Additional indicators for RQ#3 research hypothesis may result in data and findings more similar to the findings for the other three research hypotheses. The results for the RQ#3 research question focused attention on the need to review and consider changes within the McDaniel ESIL coursework addressing *Maryland State STEM SOP6* emphasizing *student collaboration as a STEM team*. Findings for the four research hypotheses will be used to reinforce and improve ESIL coursework design.

Key Assessment 3 also asked for only one coded lesson plan. A review of more than one lesson plan would provide multiple sources of evidence to address assessors' questions and broaden the opportunity for a teacher to demonstrate proficiencies in the targeted *Maryland State STEM SOP*, perhaps rendering different assessment outcomes. While a possible benefit for the sample, increasing the number of artifacts would increase the time-commitment required for the assessment team's review. While performance assessments, such as the MSDE key assessments, reinforce the constructivist learning approach within the McDaniel ESIL program and provide the opportunity for practical examples of teacher-generated knowledge, they are also time consuming to assess (Koirala, David, & Johnson, 2008). Following our training session, each of the independent assessors indicated that they spent between fourteen and sixteen hours reviewing

and scoring the remaining fourteen artifacts. The time required to assess performance-based assessments is a limitation to their use.

Despite the fact that the use of the Fleiss kappa is well-accepted as an appropriate means to assess the reliability of agreement among multiple observers and multiple categories, questions have been raised suggesting that the Fleiss kappa statistic “behaves inconsistently in cases of strong agreement among raters, resulting in lower values than would have been expected” (Falotico & Quatto, 2015, p. 463). Falotico and Quatto suggest incorporating the use of permutation techniques to eliminate what they describe as “paradoxical behavior.” While the data and findings of this study resulted in an acceptable kappa of 0.34, the researcher questions how changes in computing Fleiss kappa, an increase in the number of raters and sample size, and changes in the instrumentation may impact the data and findings.

5.5 Implications of the Study

Findings from this study, as shown by the Fleiss kappa and Wilcoxon-signed-rank statistical analyses, supported that the three assessors’ results showed consensus and indicated that the elementary teachers within the study demonstrated proficient abilities to plan lessons that addressed four *Maryland State STEM SOP*. This work provided a baseline for assessment of future cohorts, keeping in mind that abilities demonstrated by the teachers within this study were not due exclusively to the treatment protocol. Efforts to define teachers’ prior planning abilities, through pre-assessment experiences, could help isolate and document changes in teachers’ planning due to their involvement in the McDaniel ESIL program.

As a result of this study, there is evidence that the state-approved rubric for *Key Assessment 3* is a reliable metric. This performance assessment protocol frames a reliable tool and is paired with instrumentation that has reliable assessment indicators. *Key Assessment 3*

could be used as pre, formative, and summative assessment to capture teachers' continued growth in planning STEM-centric lessons. For future studies there may be consideration to modify the number of raters and subjects to determine how those changes would impact the kappa statistic.

Assessing teacher practices, such as a teacher's ability to plan lessons, requires evidence in the form of artifacts. The use of performance assessments, for this study *Key Assessment 3*, has been promoted by policy-makers to set benchmarks and initiate educational reform (Koirala et al., 2008). *Key Assessment 3* required teachers to code and analyze their lesson and reflect upon deliberate decisions demonstrated in planning the lessons. Teachers within the sample group were well prepared for this work, having practiced analytic and reflective behavior through online, asynchronous discussions within the ESIL coursework.

The McDaniel College ESIL approach paired key elements of the 1995 Haney and Lumpe Model of Professional Development with 2015 educational technology and instructional tools unavailable at the time of Haney and Lumpe's work. The hybrid nature of the coursework supports ongoing professional experiences and growth through online networking beyond the completion of coursework, using technology to provide and extend continuous and sustained professional growth through a community of learners. Online discussions promote analysis and self-reflection and provide a flexible setting for collaboration and easy sharing of resources. Developing the skills and habits for communicating online supports job-embedded learning, an essential component for teacher professional growth (Darling-Hammond, 1997; Ernst et al., 2014; Fisher, 2005; Segedin et al., 2013; Zepeda, 1999).

While the creation of a teacher leadership planning team is consistent with the Haney and Lumpe Model, the ongoing collective efforts among McDaniel College, CCPS, and NIA-CISE

extended and increased the role of a leadership team through the planning, implementation, and evaluation cycle, resulting in coherent, system-driven implementation of job-embedded learning experiences that utilized and reinforced state and systemic STEM education goals. The McDaniel College ESIL cohort model, a key component within the Haney and Lumpe Model and reinforced by *Learning Forward* (Learning Forward, 2015a), was a powerful agent of change for CCPS, increasing the county's capacity and preparing the ESIL teachers for leadership roles within their buildings and throughout the system in the form of planning and delivering professional development and writing curriculum.

These findings imply that the design and instruction of the McDaniel College ESIL coursework may have contributed to the teachers' proficiencies in planning. The deliberate and intentional design of the coursework utilized essential components identified as research-based best practice planning, implementation, and evaluation of professional learning experiences and reinforced the use of researched teacher and learning strategies as effective professional learning delivery models. The McDaniel College ESIL model is job-embedded, cohort-based, and designed as a hybrid experience to maximize flexibility, build online communication skills, and provide a platform for deeper analysis and self-reflection. Planning collaboratively with the school district assures a more coherent and systemic alignment with local, state, and national initiatives. Teachers within the ESIL program build an understanding and proficiency of inquiry and problem-based learning through the design of STEM-centric lessons that utilize the 7E Learning Cycle (Bybee, 1997; Bybee et al, 2006; Eisenkraft, 2003). Lesson design is introduced in the first course, but revisited within three subsequent courses to build the teachers proficiency in lesson design. The teachers also build their own understanding and strategies to use STEM notebooks as tools for planning, teaching, and assessment throughout the coursework.

While the ESIL coursework tightly aligns with the *Maryland State STEM SOP*, there is a strong use of the *NGSS* for lesson design. Teachers build their understanding of the *NGSS*, learning how to integrate engineering with science through active, student-centered inquiry and design-based learning framed by 7E lessons. Each course within the program deliberately builds the elementary teachers' knowledge of content and practice guided by state and national standards.

While these findings have targeted impact that could inform the design and delivery of elementary teacher education within Maryland, these findings have implications for teacher education at large. The McDaniel College ESIL model has research literature and this study's results to support changes in teacher education programs. This model could be used to frame teacher learning for in-service teachers within formal graduate studies and more informal professional learning experiences. It is also a model that could inform pre-service teacher education.

School districts within Maryland and across the country could use what has been learned to frame professional learning experiences for their teachers. The collective efforts of academia, a non-profit STEM research facility, and a local school division models the collaboration needed for transformational changes in education required to prepare our students for 21st century challenges. The essential ingredients for this level of change are embedded within the McDaniel ESIL model.

5.6 Suggestions for Further Research

This study targeted elementary teachers' abilities to plan STEM-centric lessons. As noted earlier within this chapter, the teachers within the study sample were consummate and experienced educators. Future studies might compare their results with a more novice group of

teachers. The sample population was predominantly traditionally-licensed teachers. Further research might examine the generalizability of these results for teachers earning their teaching licensing through alternative programs, such as career switchers. One might explore if the planning proficiencies demonstrated within this study are components of both traditional and non-traditional educational preparatory experiences.

Although there are distinct learner considerations, developmental needs, and age-appropriate teaching strategies, future studies could examine how the McDaniel College ESIL approach to STEM education might translate to secondary education. The McDaniel College ESIL model and framework may be as successful with secondary educators as it was found to be for the elementary educator population examined within this study.

It is an assumption that a teacher's planning will result in successful implementation of the lesson. Future studies could take two tracks to analyze the teachers' abilities to implement the lessons following proficient lesson planning. First, one study could provide the teacher-authors of the lesson the opportunity to teach their own lesson. This would assess each teacher's abilities to both plan and implement STEM-centric lessons. A second approach might assess the abilities of a second group of teachers to implement lessons developed by teachers' identified as proficient lesson planners. Slightly more than 60% of the teachers within this study have served on curriculum writing teams for the county. While this study suggests that these teachers have the ability to proficiently plan lessons, will the lessons they plan provide the guidance needed for successful implementation by other educators? It would be interesting to compare the implementation skills of the teacher-authors with teachers uninvolved in developing the lesson plans.

Future studies should explore student achievement through the implementation of STEM-centric lessons to determine how learning is impacted by STEM-centric planning and teaching. There is evidence that decisions teachers make while planning lessons impacts student learning (Lardy, 2011; Palmer, 2006). The STEM-centric lessons reviewed within this study followed the tenants of design-based learning organized within a 7E Learning Cycle. STEM notebooks were an integral part of each lesson, used for both formative and summative assessment. Future studies could focus on the effectiveness of 7E lesson design or the impact of STEM notebooks for planning, teaching, and learning.

Five of the six ESIL courses were developed by the researcher. For this study group, the researcher was the primary instructor for those five courses. To build instructional capacity, the researcher is mentoring members of the pilot cohort to become instructors within the ESIL program. McDaniel College is also recruiting other Maryland counties for future ESIL cohorts. Broadening the instructor pool and extending the courses to other counties will permit examination of the utility of the McDaniel ESIL coursework, while it introduces the challenge to maintain the integrity of the model. The goals, objectives, and assessment of the ESIL program will be maintained through the structure and framework of the coursework and key assessments.

The apparent success of the McDaniel ESIL coursework, as one factor affecting the study sample's abilities to proficiently plan STEM-centric lessons, is tied to the described limiting factors of the sample's attributes and this study's instrumentation. Future studies may provide evidence that the same levels of proficiency in planning transcend this studies' limitations.

5.7 Conclusions

Teacher quality has been cited as one of the most critical factors impacting student learning (NRC, 2010). While few attributes of effective teachers have been verified, there is

consensus that effective teachers use a variety of instructional strategies and make deliberate choices in their lesson planning that support student-centered and inquiry-based instruction (Kukla-Acevedo, 2009; Stronge et al., 2008; Wing-mui So, 1997). Elementary science instruction often lacks an inquiry and student-centered approach (Lardy, 2011). Maryland, an early adopter of the *NGSS* and leader in STEM initiatives, recognized this need for transformational professional learning experiences for elementary teachers and encouraged Maryland colleges and universities to develop programs to prepare in-service teachers to develop and implement inquiry-based STEM-centric learning experiences (MSDE, 2012). In response to this call, McDaniel College teamed with CCPS and NIA-CISE to develop the McDaniel ESIL graduate program. The purpose of this research was to add to the field's knowledge of elements in the promotion of graduate coursework that lead to elementary in-service teachers' proficiency in planning STEM-centric lessons. This was accomplished by investigating the McDaniel College ESIL pilot cohort's ability to *proficiently* plan lessons that incorporate the *Maryland State STEM SOP* targeting integration of STEM content, inquiry learning, students' abilities to collaborate and students' strategic application of technology.

The results of this study supported that the sample demonstrated proficient abilities to plan lessons that incorporated the targeted *Maryland State STEM SOP* matched with each of the four research hypotheses. These findings infer that teacher learning and growth is supported through the deliberate design and instruction of the McDaniel College ESIL coursework. The McDaniel College ESIL model, framed by the 1995 Haney and Lumpe Model of Professional Development, synthesized this model and other identified best practice approaches for planning, implementation, and evaluation of professional learning experiences. Key components of the McDaniel College ESIL Model should be considered in the design of future graduate studies and

other professional learning experiences to advance elementary STEM-centric planning. Flexible, hybrid coursework honors teachers' busy schedules. The integrated online and face-to-face instruction allows pre-assessment of the teachers' understanding of concepts prior to face-to-face meetings and provides a platform for on-going teacher self-reflection. The McDaniel College ESIL Model is pragmatic, utilizing tasks that are job-embedded and aligned with school-based initiatives, allowing for immediate application within classroom settings.

Teachers developed and implemented 7E Learning Cycle lessons that followed the tenants of problem-based learning through the use of an engineering design problem. The 7E model promotes student questioning and student-centered learning and incorporates the use of STEM notebooks as tools for pre- and formative assessment. Working through the ESIL coursework as a cohort not only helped to build capacity within the school-system, but also quickly provided a strong community of learners that continues to sustain the group.

While the sample's attributes prior to their McDaniel College ESIL coursework were impressive, their collective work following their completion of the program has confirmed their proficiencies in planning STEM-centric lessons. Key components of the McDaniel College ESIL coursework design have supported the pilot group's professional learning growth. Maryland's adoption of the *STEM SOP* and *NGSS* created a need for transformational professional learning experiences for elementary teachers to evolve their STEM planning and teaching practice. The need for such professional learning experiences, however, is not confined to Maryland. All states adopting *NGSS* need to provide targeted and coherent STEM-centric professional learning experiences for elementary teachers that address the specific needs of this population. The approach analyzed within this study provides outcomes that contribute to the knowledge base and suggest refinements of prior successful learning models through an

informed, iterative process. Beyond this study, the McDaniel College ESIL Model should be considered for all teacher education settings, including pre-service and in-service K-12 educators.

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APPENDIX A

Letter from MSDE Confirming the McDaniel College ESIL Program Approval



Lillian M. Lowery, Ed.D.
State Superintendent of Schools

200 West Baltimore Street • Baltimore, MD 21201 • 410-767-0100 • 410-333-6442 TTY/TDD • MarylandPublicSchools.org

July 22, 2015

J. Michael Tyler, PhD
Dean, Graduate and Professional Studies
McDaniel College
2 College Hill
Westminster, Maryland 21157-4390

Dear Dr. Tyler:

We have received and reviewed your request for approval of a new certification program in Elementary Science, Technology, Engineering, and Mathematics (STEM) education for practicing teachers. The following program has received approval for implementation:

Instructional Leader: STEM (PreK-6)

On behalf of the Maryland State Department of Education (MSDE), we applaud your efforts to offer one of the first state-approved programs for Elementary STEM Instructional Leader. Your partnership with Carroll County Public Schools and the National Institute of Aerospace will impact the quality and quality of effective Maryland teachers in STEM education. Thoughtful planning resulted in a program that includes performance assessments aligned with school-based needs to promote student learning in STEM.

With this approval, you can record on your graduates' transcripts they have completed a "Maryland Approved Program in Instructional Leader: Elementary STEM (PreK-6)." Systems should be in place to collect and report data that will provide valuable information on candidate performance on the program assessments. We look forward to hearing about the initial progress of your program at the time of your joint State/CAEP accreditation visit scheduled for spring 2016.

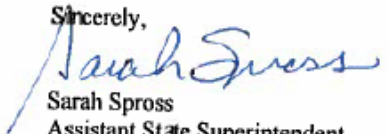
Again, we would like to recognize McDaniel College for being a leader in our state to prepare teachers with the skills to integrate and deliver STEM education to children in both elementary and early childhood grades.

MarylandPublicSchools.org

Dr. J. Michael Tyler
July 22, 2015
Page 2

If you have any questions, please contact your program approval liaison, Ms. Michelle Dunkle, at 410-767-0390.

Sincerely,



Sarah Spross
Assistant State Superintendent
Division of Educator Effectiveness

c: Dr. Daria Buese
Ms. Michelle Dunkle

APPENDIX B

Letter from Maryland Higher Education Commission Confirming the
McDaniel College ESIL Program Approval



Larry Hogan
Governor
Boyd K. Rutherford
Lt. Governor
Anwar Hasan
Chairperson
Jennie C. Hunter-Cevera
Acting Secretary

July 21, 2015

Dr. Julia Jasken
Provost
McDaniel College
2 College Hill
Westminster, MD 21157

Dear Dr. Jasken:

The Maryland Higher Education Commission has reviewed a request from McDaniel College to add the Post-Baccalaureate Certificate (P.B.C.) in Elementary STEM Instructional Leader to the Academic Program Inventory of the Maryland Higher Education Commission. I am pleased to inform you that this addition has been administratively approved. This decision is based on documentation that this certificate program has been in existence and was activated prior to 2012.

For purposes of providing enrollment and degree data to the Commission in the future, please use the following HEGIS and CIP codes:

Program Title	Award Level	HEGIS	CIP
Elementary STEM Instructional Leader	P.B.C	0899-01	13.0404

Should McDaniel College desire to make a substantial modification to the program in the future, review by the Commission will be necessary. I wish you continued success.

Sincerely,

Jennie C. Hunter-Cevera, Ph.D.
Acting Secretary of Higher Education

JCHC:mw

C: Ms. Diane C. Hampton, Director of Institutional Relations, MICUA
Jennifer Frank, Assistant Secretary, MHEC
Monica Wheatley, Associate Director of Collegiate Affairs, MHEC
Geoffrey Newman, Finance Policy Director, MHEC
Anthony Reiner, Finance and Facilities, MHEC

APPENDIX C

Maryland State Department of Education State STEM Standards of Practice (SOP) (MSDE, 2013b)

Standard of Practice	Description
SOP1	<p>Learn and Apply Rigorous Science, Technology, Engineering and Mathematics Content</p> <p>STEM proficient students will learn and apply rigorous content within science, technology, engineering, and mathematics disciplines to answer complex questions, to investigate global issues, and to develop solutions for challenges and real world problems.</p> <p>A. Demonstrate an understanding of science, technology, engineering, and mathematics content.</p> <p>B. Apply science, technology, engineering, or mathematics content to answer complex questions, to investigate global issues, and to develop solutions for challenges and real world problems.</p>
SOP2	<p>Integrate Science, Technology, Engineering, and Mathematics Content</p> <p>STEM proficient students will integrate content from science, technology, engineering, and mathematics disciplines as appropriate to answer complex questions, to investigate global issues, and to develop solutions for challenges and real world problems.</p> <p>A. Analyze interdisciplinary connections that exist within science, technology, engineering, and mathematics disciplines and other disciplines.</p> <p>B. Apply integrated science, technology, engineering, mathematics content, and other content as appropriate to answer complex questions, to investigate global issues, and to develop solutions for challenges and real world problems.</p>
SOP3	<p>Interpret and Communicate Information from Science, Technology, Engineering, and Mathematics</p> <p>STEM proficient students will interpret and communicate information from science, technology, engineering, and mathematics to answer complex questions, to investigate global issues, and to develop solutions for challenges and real world problems.</p>

- A. Identify, analyze, and synthesize appropriate science, technology, engineering, and mathematics information (text, visual, audio, etc.).
- B. Apply appropriate domain-specific vocabulary when communicating science, technology, engineering, and mathematics content.
- C. Engage in critical reading and writing of technical information.
- D. Evaluate and integrate multiple sources of information (e.g.: quantitative data, video and multimedia) presented in diverse formats.
- E. Develop an evidence-based opinion or argument.
- F. Communicate effectively and precisely with others.

SOP4 Engage in Inquiry

STEM proficient students will engage in inquiry to investigate global issues, challenges, and real world problems.

- A. Ask questions to identify and define global issues, challenges, and real world problems.
- B. Conduct research to refine questions and develop new questions.

SOP5 Engage in Logical Reasoning

STEM proficient students will engage in logical reasoning to answer complex questions, to investigate global issues, and to develop solutions for challenges and real world problems.

- A. Engage in critical thinking.
- B. Evaluate, select, and apply appropriate systematic approaches (scientific and engineering practices, engineering design process, and/or mathematical practices).
- C. Apply science, technology, engineering, and mathematics content to construct creative and innovative ideas.
- D. Analyze the impact of global issues and real world problems at the local, state, national, and international levels.

SOP6 Collaborate as a STEM Team

STEM proficient students will collaborate as a STEM team to answer complex questions, to investigate global issues, and to develop solutions for challenges and real world problems.

- A. Identify, analyze, and perform a STEM specific subject matter expert (SME) role.
- B. Share ideas and work effectively with a STEM focused multidisciplinary team to achieve a common goal.
- C. Listen and be receptive to ideas of others.
- D. Analyze career opportunities that exist in a variety of STEM fields

relevant to the STEM focused multidisciplinary team's goal.

SOP7

Apply Technology Strategically

STEM proficient students will apply technology appropriately to answer complex questions, to investigate global issues, and to develop solutions for challenges and real world problems.

- A. Identify and understand technologies needed to develop solutions to problems or construct answers to complex questions.
- B. Analyze the limits, risks, and impacts of technology.
- C. Engage in responsible/ethical use of technology.
- D. Improve or create new technologies that extend human capability.

APPENDIX D

Key Assessment 3: Competency in Planning (McDaniel College, 2015b)

SOP 2 – *Integrate Science, Technology, Engineering and Mathematics Content*

- A. *Analyze interdisciplinary connections that exist within science, technology, engineering and mathematics disciplines and other disciplines.*
- B. *Learner can apply integrated science, technology, engineering, and mathematics content to answer complex questions, to investigate global issues, and to develop solutions for challenges and real world problems.*

SOP 4 – *Engage in Inquiry*

- A. *Ask questions to identify and define global issues, challenges, and real world problems.*
- B. *Conduct research to refine questions and develop new questions.*

SOP 6 – *Collaborate as a STEM Team*

- A. *Identify, analyze and perform a STEM specific subject matter expert (SME) role.*
- B. *Share ideas and work effectively with a STEM focused multidisciplinary team to achieve a common goal.*
- C. *Listen to and be receptive to ideas of others.*
- D. *Analyze career opportunities that exist in a variety of STEM fields relevant to the STEM focused multidisciplinary team to achieve a common goal.*

SOP 7 – *Apply Technology Strategically*

- A. *Identify and understand technologies needed to develop solutions to problems or construct answers to complex questions.*
- B. *Analyze the limits, risks and impacts of technology*
- C. *Engage in responsible/ethical use of technology.*
- D. *Improve or create new technologies that extend human capability.*

During **STM 505: Facilitating STEM Education Professional Learning** you will create a 7E lesson to demonstrate your competency in planning STEM-centric lessons using **STEM Standards of Practice 2, 4, 6, and 7**. The course instructor must approve the lesson plan used in this key assessment.

The objective of this assignment is for you to demonstrate proficiency in planning lessons which:

- **engage students in exploring and developing an understanding of STEM content by using a transdisciplinary approach to solve authentic problems.**
- **require students to ask questions and use STEM content and practices to extend their learning to new problems or situations.**
- **build opportunities for students to work collaboratively as a STEM team.**
- **require students to apply technology as needed to develop solutions.**
- **employ comprehensive evaluation of student progress through pre, formative and summative assessments.**

Task: Review and evaluate a transdisciplinary lesson that gives your students opportunities to explore and integrate science, technology, engineering and mathematics content while solving relevant problems, complex questions, global issues and/or authentic challenges. The lesson plan should include:

- **opportunities for students to engage in inquiry.**
- **opportunities for students to collaborate as a STEM team.**
- **opportunities for students to apply technologies strategically.**
- **comprehensive evaluation of student progress through pre, formative and summative assessments.**

Review the 7E lesson that you selected and reflect on its quality. Use the “*Insert Comment*” feature in Microsoft Word to identify examples of STEM-centric practices and assessments within the 7E lesson plan. Identify specific examples in the lesson design of how you planned for the indicators for the Maryland State STEM Standards of Practice 2, 4, 6 and 7 and how you assessed them.

Within the “Insert Comment” code the examples to show:

SOP2A, SOP2B – Integrated science, technology, engineering content

SOP4A, SOP4B – Inquiry

SP6A, SOP6B, SOP6C, SOP6D – Collaboration

SOP7A, SOP7B, SOP7C, SOP7D – Application of technology

Write a reflection paper that describes how your lesson planning developed and evolved as a result of your studies within the McDaniel College Elementary STEM Instructional Leader Program. Include a defense (include authoritative support) to justify how your lesson demonstrates STEM SOP 2, 4, 6, and 7. In addition to a general reflection on your lesson planning, you must address the following questions in your narrative:

- **How would you improve the lesson based upon the STEM Standards of Practice indicators?**
- **How did your assessments inform instruction?**

Assessment Criteria: Your work will be scored using the following rubric. An overall score for the coding of your artifacts and reflection paper will be determined using the following criteria: Exemplary: 40-52 (with no areas in the developing or unsatisfactory range)

Proficient: 27-39 (with no areas in the unsatisfactory range)

Developing: 14-26

Unsatisfactory: 13

Key Assessment 3 Rubric

Assessment of Competence in Planning	Exemplary (4)	Proficient (3)	Developing (2)	Unsatisfactory (1)
<p>(A) Lesson engages students in exploring and developing understanding of STEM content and provides them with opportunities to apply STEM content and practices to solve authentic problems.</p>	<p>(A1) The lesson includes opportunities for students to engage in the inquiry necessary to answer <i>their own questions</i> about complex questions, global issues, and/or real world challenges.</p>	<p>(A1) The lesson plan includes experiences in which content standards are developed to <i>help students make connections</i> between content and a complex question, global issue, and/or real world challenge.</p>	<p>(A1) The lesson plan includes <i>teacher directed experiences in which content standards are developed with some student involvement.</i></p>	<p>(A1) The lesson plan includes <i>teacher directed</i> experiences in which content standards are developed <i>using lecture and step-by-step investigations.</i></p>
	<p>(A2) The learning experience is <i>driven by students</i> making connections between disciplinary content knowledge and practices.</p>	<p>(A2) The learning experience is <i>guided by the teacher</i> where disciplinary content knowledge and practices are integrated. The teacher considers student interests.</p>	<p>(A2) The learning experience develops content knowledge <i>without meaningful integration. Practices of the discipline are limited.</i></p>	<p>(A2) The learning experience develops content knowledge in <i>isolation of other disciplines. Opportunities to use the practices of the discipline are not evident</i> in the lesson plan.</p>
	<p>(A3) The lesson plan suggests how students work in formally structured teams with clearly defined expectations for individual and team accountability, but allows for <i>students to take ownership</i> in how their work is planned and structured. The collaborative group functions in a similar manner to a real-world collaborative team.</p>	<p>(A3) The lesson plan describes how students work in formally structured teams with clearly defined expectations for individual and team accountability.</p>	<p>(A3) The lesson plan suggests that students work in collaborative teams, but <i>expectations are not clearly defined.</i></p>	<p>(A3) The lesson plan only includes opportunities for <i>students to work alone or instruction is teacher directed to the whole group.</i></p>

	(A4) The lesson plan describes learning experiences where <i>students select technology tools and use them creatively</i> to develop solutions to problems and/or construct answers to complex questions.	(A4) The lesson plan describes learning experiences where <i>students use technology tools</i> to help them develop solutions to problems and/or construct answers to complex questions.	(A4) The lesson plan describes learning experiences where <i>only the teacher uses technology tools</i> .	(A4) The lesson plan describes learning experiences <i>devoid of technology tools</i> .
	(A5) The lesson plan describes learning experiences that provide students with opportunities to develop science and engineering practices as they seek answers to thoughtful <i>questions they have developed</i> , define complex problems, develop and use models, and plan and carry out investigations.	(A5) The lesson plan describes learning experiences that <i>the teacher guides</i> , which lead students to use the practices of the STEM disciplines, such as asking questions, defining problems, using models, and carrying out investigations.	(A5) The lesson plan describes learning experiences where <i>the teacher models the use of the practices of the STEM disciplines</i> , but students have limited opportunities to use the practices themselves.	(A5) The lesson plan describes traditional learning experiences where <i>only the teacher uses the practices of the STEM disciplines</i> . Content is discrete (not integrated) and teacher directed.
(B) Lesson requires students to use STEM content and practices to extend their learning to new problems or situations	(B1) Within the lesson, students are asked to <i>systematically analyze</i> the limits, risks, and impacts of technology and to defend their findings.	(B1) Within the lesson, students are asked to <i>consider</i> the limits, risks, and impacts of technology.	(B1) Within the lesson, the <i>teacher explains</i> to the students the limits, risks and impacts of technology.	(B1) Limits, risks and impacts of technology are <i>not addressed</i> within the lesson.
	(B2) Within the lesson, students are asked to <i>improve or create</i> a new technology to extend human capability.	(B2) Within the lesson, students are asked to <i>imagine/plan</i> a new technology to extend human capability.	(B2) Within the lesson, the <i>teacher suggests how to</i> create a new technology to extend human capability.	(B2) Within the lesson, students use only <i>existing technology</i> as it is currently used without suggestions for improvements or modifications.
	(B3) The lesson requires students to effectively	(B3) The lesson requires students to effectively	(B3) The lesson requires students to communicate their	(B3) There are <i>limited opportunities</i> for students to

	communicate their understanding of the STEM content by developing an evidence-based argument that <i>addresses multiple perspectives</i> of an issue or problem.	communicate their understanding of the STEM content by developing an evidence-based <i>argument appropriate to students' grade level</i> .	understanding of STEM content by <i>responding to teacher-developed questions</i> .	demonstrate their understanding of STEM content in the lesson.
	(B4) The lesson plan includes engaging, open-ended pre-assessment of students' prior understanding of content knowledge in the context of a <i>real situation</i> .	(B4) The lesson plan includes engaging, open-ended pre-assessment of students' prior understanding of content knowledge.	(B4) The lesson plan includes a pre-assessment, which takes the form of a <i>traditional assessment</i> . Assessment is specific to a STEM content discipline. <i>Items are limited and have limited opportunities for higher level thinking to be demonstrated</i> .	(B4) The lesson plan <i>does not consider pre-assessment</i> of students' prior understanding of content knowledge.
(C) Lesson comprehensively evaluates student progress (including pre, formative and summative assessment)	(C1) The lesson plan is designed to offer students multiple opportunities to demonstrate their understanding of the STEM content by recalling and applying concepts and providing them an <i>opportunity to discuss how their learning evolved</i> .	(C1) The lesson plan is designed to offer students multiple opportunities to demonstrate their understanding of the STEM content by recalling and applying concepts.	(C1) The lesson plan has <i>limited opportunities</i> for students to demonstrate their understanding of STEM content. These opportunities rely heavily on the <i>recall</i> of information, with <i>very little application</i> of concepts.	(C1) The lesson plan includes <i>only</i> a summative assessment at the end of the lesson.
	(C2) STEM notebooks are used to <i>inculcate habits of mind</i> that permit students to demonstrate a <i>comprehensive understanding</i> of STEM content	(C2) STEM notebooks are used <i>purposefully</i> to permit students to demonstrate an <i>accurate understanding</i> of STEM content.	(C2) STEM notebooks are used as a <i>tool</i> for students to <i>record their observations and material that the teacher deems important</i> .	(C2) There are <i>few references</i> as to how STEM notebooks will be used to demonstrate students understanding of STEM content.

	through <i>evidence-based arguments</i> .			
(D) The narrative describes the candidate's knowledge and application of STEM-centric planning.	(D1) Reflection shows <i>substantial</i> evidence of synthesis of STEM Standards of Practice 2,4,6, and 7 presented in the STEM Instructional Leader Program.	(D1) Reflection shows evidence of synthesis of STEM Standards of Practice 2,4,6, and 7 presented in the STEM Instructional Leader Program.	(D1) Reflection shows <i>limited</i> evidence of synthesis of STEM Standards of Practice 2,4,6, and 7 presented in the STEM Instructional Leader Program.	(D1) Reflection shows <i>little or no evidence</i> of synthesis of STEM Standards of Practice 2,4,6, and 7 presented in the STEM Instructional Leader Program.
	(D2) The reflection on this lesson plan is guided by <i>critical insights</i> developed throughout the STEM Instructional Leader Program.	(D2) Reflection on this lesson plan is guided by <i>insights</i> developed throughout the STEM Instructional Leader Program.	(D2) Reflection on this lesson plan <i>lacks important insights</i> from the STEM Instructional Leader Program.	(D2) <i>Insight development</i> based on learning from the STEM Instructional Leader Program is <i>not evident</i> .

APPENDIX E

Standards of Technological Literacy and Benchmarks 8, 9, 10, and 11 (ITEEA, 2000)

Benchmarks	
8: Students will develop an understanding of the attributes of design.	K-2A: Everyone can design solutions to a problem. K-2B: Design is a creative process. 3-5C: The design process is a purposeful method of planning practical solutions to problems. 3-5D: Requirements for a design include such factors as the desired elements and features of a product or system or the limits that are placed on the design.
9: Students will develop an understanding of engineering design.	K-2A: The engineering design process includes identifying a problem, looking for ideas, developing solutions, and sharing solutions with others. K-2B: Expressing ideas to others verbally and through sketches and models is an important part of the design process. 3-5C: The engineering design process involves defining a problem, generating ideas, selecting a solution, testing the solution(s), making the item, evaluating it, and presenting the results. 3-5D: When designing an object, it is important to be creative and consider all ideas. 3-5E: Models are used to communicate and test design ideas and processes.
10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.	K-2A: Asking questions and making observations helps a person to figure out how things work. K-2B: All products and systems are subject to failure. Many products and systems, however, can be fixed. 3-5C: Troubleshooting is a way of finding out why something does not work so that it can be fixed. 3-5D: Invention and innovation are creative ways to turn ideas into real things. 3-5E: The process of experimentation, which is common in science, can also be used to solve technological problems.

11: Students will develop the abilities to apply the design process.

K-2A: Brainstorm people's needs and wants and pick some problems that can be solved through the design process.

K-2B: Build or construct an object using the design process.

K-2C: Investigate how things are made and how they can be improved.

3-5D: Identify and collect information about everyday problems that can be solved by technology, and generate ideas and requirements for solving a problem.

3-5E: The process of designing involves presenting some possible solutions in visual form and then selecting the best solution(s) from many.

3-5F: Test and evaluate the solutions for the design problem.

3-5G: Improve the design solutions.

APPENDIX F

Web Form Used to Gather Sample's Demographics



Wrap-up STM 505/506 Data Collection

* Required

Name *

Please write your name as you would like it to appear on the McDaniel College Elementary STEM Instructional Leader Certificate.

Current Grade You Teach *

Please identify the current grade you teach. You may select more than one grade if applicable.

Kindergarten

First

Second

Third

Fourth

Fifth

Other:

Years in the Teaching Profession *

Please indicate the years you have worked in the teaching profession.

- 1 - 5 years
- 6 - 10 years
- 11 - 15 years
- 16 - 20 years
- 20 - 25 years
- >25 years

Undergraduate Degree *

Please list your undergraduate degree major and minor (if applicable)

Graduate Degree

If applicable, please list your graduate degree and area of concentration.

Leadership Roles *

Please list any leadership roles you held during the time you have been in the STEM cohort. These may include being a team leader, curriculum writer, holding a position on school-wide or county-wide committees, etc.

- Grade level team leader
- Curriculum writer
- Parent-teacher association leadership positions
- None
- Other:

Please indicate the last course you have completed in the Elementary STEM Instructional Leader program. *

- STM 505 was my last course in the series.
- STM 506 was my last course in the series.

[Continue »](#)



Wrap-up STM 505/506 Data Collection

* Required

Additional Questions for STM 506 Participants

STM 506 Digital Portfolio LiveBinder *

Please list the url and access code for your STM 506 Digital Portfolio LiveBinder.

Key Assessment 3 *

Sharon needs "written" consent to use your Key Assessment 3 as part of her doctoral study. Your work will be anonymous in her study. Please indicate your consent by checking "yes, I grant permission" below.

- Yes, I grant permission for my Key Assessment 3 to be used in Sharon Bowers' doctoral study.
- No, I do NOT grant permission for my Key Assessment 3 to be used in Sharon Bowers' doctoral study.

[« Back](#)

[Submit](#)

Never submit passwords through Google Forms.

APPENDIX G

IRB Approval Letter



Office of Research Compliance
Institutional Review Board
North End Center, Suite 4120, Virginia Tech
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website <http://www.irb.vt.edu>

MEMORANDUM

DATE: July 2, 2014
TO: Jeremy V Ernst, Sharon Wensel Bowers
FROM: Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)
PROTOCOL TITLE: McDaniel Elementary STEM Program
IRB NUMBER: 14-655

Effective July 2, 2014, the Virginia Tech Institutional Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

<http://www.irb.vt.edu/pages/responsibilities.htm>

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As: Exempt, under 45 CFR 46.110 category(ies) 2
Protocol Approval Date: July 2, 2014
Protocol Expiration Date: N/A
Continuing Review Due Date*: N/A

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

Date*	OSP Number	Sponsor	Grant Comparison Conducted?

* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this IRB protocol is to cover any other grant proposals, please contact the IRB office (irbadmin@vt.edu) immediately.

APPENDIX H

Agenda for Assessor Training

August 1, 2015

- Overview of the study and the role and responsibilities of the assessors
- Introduce and explore the Key Assessment 3 LiveBinder

- Review Maryland's State STEM Standards of Practice
- Review the Key Assessment 3 Task and Rubric
- Practice scoring first anchor example
 - Assessors score example independently
 - Assessors share results
 - Discussion to find consensus

- Practice scoring second anchor example
 - Independent scoring
 - Shared Results
 - Consensus

- Discuss timeline for completing the remaining 14 key assessments

- Questions?

APPENDIX I

Key Assessment 3 Rubric Indicators Matched with Research Questions

<p>RQ#1: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>integrate science, technology, engineering, and mathematics disciplines</i>?</p>	<p>(A2) The learning experience is <i>driven by students</i> making connections between disciplinary content knowledge and practices.</p>	<p>(A2) The learning experience is <i>guided by the teacher</i> where disciplinary content knowledge and practices are integrated. The teacher considers student interests.</p>	<p>(A2) The learning experience develops content knowledge <i>without meaningful integration</i>. <i>Practices of the discipline are limited</i>.</p>	<p>(A2) The learning experience develops content knowledge in <i>isolation of other disciplines</i>. <i>Opportunities to use the practices of the discipline are not evident in the lesson plan</i>.</p>
	<p>(C1) The lesson plan is designed to offer students multiple opportunities to demonstrate their understanding of the STEM content by recalling and applying concepts and providing them an <i>opportunity to discuss how their learning evolved</i>.</p>	<p>(C1) The lesson plan is designed to offer students multiple opportunities to demonstrate their understanding of the STEM content by recalling and applying concepts.</p>	<p>(C1) The lesson plan has <i>limited</i> opportunities for students to demonstrate their understanding of STEM content. These opportunities rely heavily on the <i>recall</i> of information, with <i>very little application</i> of concepts.</p>	<p>(C1) The lesson plan includes <i>only</i> a summative assessment at the end of the lesson.</p>
	<p>(C2) STEM notebooks are used to <i>inculcate habits of mind</i> that permit students to demonstrate a <i>comprehensive understanding</i> of</p>	<p>(C2) STEM notebooks are used <i>purposefully</i> to permit students to demonstrate an <i>accurate understanding</i> of STEM</p>	<p>(C2) STEM notebooks are used as a <i>tool</i> for students to <i>record their observations and material that the teacher deems</i></p>	<p>(C2) There are <i>few references</i> as to how STEM notebooks will be used to demonstrate students understanding</p>

	STEM content through <i>evidence-based arguments</i> .	content.	<i>important.</i>	of STEM content.
RQ#2: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>engage students in inquiry</i> ?	(A1) The lesson includes opportunities for students to engage in the inquiry necessary to answer their own questions about complex questions, global issues, and/or real world challenges.	(A1) The lesson plan includes experiences in which content standards are developed to help students make connections between content and a complex question, global issue, and/or real world challenge.	(A1) The lesson plan includes <i>teacher directed experiences in which content standards are developed with some student involvement.</i>	(A1) The lesson plan includes <i>teacher directed</i> experiences in which content standards are developed using <i>lecture and step-by-step investigations.</i>
	(A5) The lesson plan describes learning experiences that provide students with opportunities to develop science and engineering practices as they seek answers to thoughtful <i>questions they have developed</i> , define complex problems, develop and use models, and plan and carry out investigations.	(A5) The lesson plan describes learning experiences that <i>the teacher guides</i> , which lead students to use the practices of the STEM disciplines, such as asking questions, defining problems, using models, and carrying out investigations.	(A5) The lesson plan describes learning experiences where the <i>teacher models the use</i> of the practices of the STEM disciplines, but students have limited opportunities to use the practices themselves.	(A5) The lesson plan describes traditional learning experiences where <i>only the teacher</i> uses the practices of the STEM disciplines. Content is discrete (not integrated) and teacher directed.

<p>RQ#3: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>support student collaboration as a STEM team?</i></p>	<p>(A3) The lesson plan suggests how students work in formally structured teams with clearly defined expectations for individual and team accountability, but allows for <i>students to take ownership</i> in how their work is planned and structured. The collaborative group functions in a similar manner to a real-world collaborative team.</p>	<p>(A3) The lesson plan suggests how students work in formally structured teams with clearly defined expectations for individual and team accountability, but allows for <i>students to take ownership</i> in how their work is planned and structured. The collaborative group functions in a similar manner to a real-world collaborative team.</p>	<p>(A3) The lesson plan suggests how students work in formally structured teams with clearly defined expectations for individual and team accountability, but allows for <i>students to take ownership</i> in how their work is planned and structured. The collaborative group functions in a similar manner to a real-world collaborative team.</p>	<p>(A3) The lesson plan suggests how students work in formally structured teams with clearly defined expectations for individual and team accountability, but allows for <i>students to take ownership</i> in how their work is planned and structured. The collaborative group functions in a similar manner to a real-world collaborative team.</p>
<p>RQ#4: To what extent are teachers within the McDaniel College pilot cohort proficient in developing lessons that <i>support students' strategic application of technology?</i></p>	<p>(A4) The lesson plan describes learning experiences where <i>students select technology tools and use them creatively</i> to develop solutions to problems and/or construct answers to complex questions.</p>	<p>(A4) The lesson plan describes learning experiences where <i>students use technology tools to help them develop solutions to problems and/or construct answers to complex questions.</i></p>	<p>(A4) The lesson plan describes learning experiences where <i>only the teacher uses technology tools.</i></p>	<p>(A4) The lesson plan describes learning experiences <i>devoid of technology tools.</i></p>
	<p>(B1) Within the lesson, students are asked to <i>systematically analyze</i> the limits, risks, and</p>	<p>(B1) Within the lesson, students are asked to <i>consider</i> the limits, risks, and impacts of</p>	<p>(B1) Within the lesson, the <i>teacher explains</i> to the students the limits, risks and impacts of</p>	<p>(B1) Limits, risks and impacts of technology are <i>not addressed</i> within the</p>

	impacts of technology and to defend their findings.	technology.	technology.	lesson.
	(B2) Within the lesson, students are asked to <i>improve or create</i> a new technology to extend human capability.	(B2) Within the lesson, students are asked to <i>imagine/plan</i> a new technology to extend human capability.	(B2) Within the lesson, the <i>teacher suggests how to</i> create a new technology to extend human capability.	(B2) Within the lesson, students use only <i>existing technology</i> as it is currently used without suggestions for improvements or modifications.

Appendix J

Screenshot of the LiveBinder Used by Assessors

Analysis of Key Assessment Three: Dissertation Data Collection
By: cwbowers

Training Agenda	Maryland STEM Standards of Practice	Key Assessment 3 and Rubric	
Assessors' Rubric	Teacher 1 -- Grade 5	Teacher 2 -- Grade 3	Teacher 3 -- Grade 4
Teacher 4 -- Grade 2	Teacher 5 -- Grade 4	Teacher 6 -- Grades 5/6	Teacher 7 -- Grade 2
Teacher 8 -- Grade 4	Teacher 9 -- Grade 5	Teacher 10 -- Grade 5	Teacher 11 -- Grade 1
Teacher 12 -- Grade 2	Teacher 13 -- Grade 5	Teacher 14 -- Grade 1	
Teacher 15 -- Grade 4	Teacher 16 -- Grade 5	McDaniel ESIL Program	

<http://www.livebinders.com/media/get/MTlwMTg4OTk=>

Assessor Training
August 1, 2015

- Overview of the study and the role and responsibilities of the assessors
- Introduce and explore the Key Assessment 3 LiveBinder
- Review Maryland's STEM Standards of Practice
- Review the Key Assessment 3 Task and Rubric
- Practice scoring first anchor example
 - Assessors score example independently
 - Assessors share results
 - Discussion to find consensus

APPENDIX K

Sample Coded Lesson for Key Assessment 3

7E Inquiry-Based Lesson Spring Garden's Outdoor Classroom

NGSS:

3-5-
ETS1-1.

Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-
ETS1-2.

Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-
ETS1-3.

Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

4-ESS2-
1.

Make observations and/or measurements to provide evidence of the effects of weathering or the rate of erosion by water, ice, wind, or vegetation.

Author
Science content

CCPS Science Curriculum:

- Recognize and explain how physical weathering and erosion cause changes in the Earth's surface.
- Describe how weathering wears down Earth's surface: Water, Ice, wind
- Cite evidence to show that erosion shapes and reshapes the Earth's surface as it moves Earth's materials from one location to another (water, ice, wind)
- Cite examples that demonstrate how the natural agents of wind, water and ice produce slow changes on the Earth's surface.
- Describe ways that the following processes contribute to changes always occurring to the Earth's surface: erosion, transportation, deposit

Author
Science content

Engage

Two years ago, Spring Garden's fifth grade students designed and planted an

Author
Real-world problem/authentic problem

afforestation area on our school grounds. The trees they planted are now well established and are thriving. When the trees were planted the students purposefully left a center area unplanted, as an outdoor classroom space.

Design Challenge:

Now it is your turn to be environmental scientists and design Spring Garden's outdoor classroom. While the open, grassy area in our afforestation area is beautiful, it is not conducive to outdoor learning.

You will work in small groups, as a STEM team, to design an outdoor classroom space that can accommodate a class of children while providing group seating and a tool for teachers to use outside, like an indoor chalkboard. A major consideration must be the effect of weathering and erosion on the materials used in your design.

Your group will plan, research and sketch your design before presenting it to a panel of experts in three weeks.

Author
Real-world problem/authentic problem

Elicit

Show the [Animoto video](#) so students can learn more about the environmental scientist STEM career.

Author
SOP 6D – analyze career opportunities

As students eagerly begin thinking about their design challenge, elicit their ideas and record on a class chart as shown below. (Sample ideas and questions shown.)

Author
This is an initial form of pre-assessment. From the types of questions the students ask, the teacher can determine his/her next steps.

Outdoor Classroom Design Challenge	
What we Know	What we need to Know
<ul style="list-style-type: none"> Outdoor classroom is in afforestation area on side of school property 	<ul style="list-style-type: none"> Exactly what is an outdoor classroom? Who will use our outdoor classroom? What will they use it for? What would they like to have in the outdoor classroom?
<ul style="list-style-type: none"> We get to design it! 	<ul style="list-style-type: none"> What is weathering and how do we prevent it?
<ul style="list-style-type: none"> Our design has to "hold up" in the weather (weathering/erosion) 	<ul style="list-style-type: none"> What is erosion and how do we prevent it?
<ul style="list-style-type: none"> It has to last 	<ul style="list-style-type: none"> What materials can we use to make our seats? Teacher tool?
<ul style="list-style-type: none"> We need seats and a display board for the teacher 	<ul style="list-style-type: none"> How much will this cost? Where will we get the money?
<ul style="list-style-type: none"> Needs to be useful 	<ul style="list-style-type: none"> How will we design the area?

Author
SOP 4A – asking questions to identify and define the real-world problem/challenge

Explore

Explore

1. Allow students to choose their own STEM teams, made of 3-4 students, to work with for this project. These will be their design groups.

2. Reviewing the "What we need to Know" side of the chart above, it's evident that the students have many questions to be answered.

3. Take the students outside to the afforestation area and have them find the outdoor classroom space.

a. Students will have trouble finding the space because it is just a grassy area in the middle of the tree planting area.

b. Discuss how the area could be used as an outdoor classroom - students may mention that classes could use the area to observe nature, read, sketch, gather in groups, etc.

c. Discuss how the area could be made more user friendly - students may suggest seating, paths, signs, etc.

d. Ask - what information would we need to collect from this space in order to provide a user-friendly outdoor classroom space? Students may suggest finding the measurements of the length, width, perimeter, area, etc.

e. Using a meter wheel, have students measure the dimensions of the outdoor classroom space. Students should draw the classroom shape and label its dimensions as they are measured. This will be used during the design challenge.

4. Explain to the students that they will be dividing up the work, in order to make efficient use of their time. One member from each STEM team will research different aspects of this project (inquiry groups), including:

- Stakeholder considerations
- Weathering and erosion
- Landscaping and building materials

4. Meet with each inquiry group to help students plan how they will begin their research:

Inquiry Essential Feature #1 - Learner engages in scientifically oriented questions.
(Questions students posed as they began their inquiry are shown in red below.)

Author

SOP 6B - share ideas and work effectively with a STEM focused, multidisciplinary team to achieve a common goal, which in this case is the outdoor classroom design.

Author

SOP 4A - here the teacher is guiding the students to ask questions which will help them further identify and define the real-world problem (outdoor classroom design).

Author

SOP 6A - identify, analyze and perform a STEM specific subject matter expert role

Author

SOP 4A - the teacher sets up initial inquiry groups to help guide them as they begin research.

Author

SOP 4A

- Stakeholder considerations - Students will need to consider both the teachers' and students' needs and wishes for the outdoor space. This can be accomplished through a survey (paper/pencil, interview or www.surveymonkey.com).

Who are our stakeholders for this project? Who in our school will be using the outdoor classroom space? How would they like to use the space? What things would they like to have in that space?

- Weathering and erosion - Students will need to research these processes in order to define them, provide examples of each and suggest ways to prevent them.

What is weathering? What is erosion? Why is weathering or erosion important to our outdoor classroom design? What causes weathering and erosion?

- Landscaping & building materials - Students will need to become familiar with common materials used in outdoor construction. Consideration should be given to availability of resources (partnership with Lowe's through grant), cost of materials, and how well each type of material holds up (weathering/erosion).

What materials can be used outside to make seats or a display board? What materials withstand weathering and erosion best? What do the materials cost? What do these materials look like? What are they made of? How are they sold (in what dimensions, quantities, etc)?

5] Once expert groups have an understanding of their tasks, provide students with the materials necessary to conduct their research and the time to do so:

- Stakeholder Considerations - this group needed access to a computer in order to draft questions for staff/students, distribute the survey, compile results and share results with the rest of the class.
- Weathering and Erosion - this group needed access to the Discovery Education website and the school library to conduct their research.
- Landscaping & Building Materials - this group needed access to the Lowe's website as well as samples of a variety of building materials such as Trex, vinyl, treated lumber, plain lumber and Azek (another brand of composite material).

Author
BOP 4B - conduct research to refine questions and develop new questions.

<p>6. While students are working in their expert groups, the teacher should monitor discussions, only joining in when students need help to navigate a website or need to keep the conversation going. At this point the teacher is facilitating the students' inquiry of their particular research topic.</p>	<p>Author SOP 4B – students working in Inquiry groups (STEM teams) to conduct research.</p>
<p><i>Inquiry Essential Feature #2 - Learner gives priority to evidence in responding to questions.</i></p>	<p>Author SOP 4</p>
<p>7. After two class periods of research time, each expert group needs to compile their information, to prepare for reporting back to their outdoor classroom design groups.</p>	<p>Author SOP 6B – first the expert groups are sharing ideas within expert groups then meeting with their design groups to communicate what they learned</p>
<p>8. Other options for students to explore the topics of weathering and erosion are available from the CCPS 5th grade science curriculum, including the Wind Erosion and Water Erosion lab sheets. See pages 17-20. These are used as formative assessments to make sure students are grasping the concepts shared from the expert groups and to provide students with hands-on experiences with weathering/erosion.</p>	<p>Author These can be used as formative assessment. The same information can also be recorded in students' STEM notebooks rather than recording on separate paper.</p>
<p><u>Explain</u></p>	
<p><i>Inquiry Essential Feature #3 - Learner formulates explanations from evidence.</i></p>	<p>Author SOP 4B</p>
<p><i>Inquiry Essential Feature #4 - Learner connects explanations to scientific knowledge.</i></p>	
<p>1. Within outdoor classroom design groups (see explore #1), students will take one class period to report findings from their expert group. Each design group will be responsible for utilizing information learned from each expert group in their outdoor classroom design.</p>	<p>Author SOP 6B see comment #15 above</p>
<p>2. Within students' STEM notebooks, students must respond to the following questions:</p> <ul style="list-style-type: none"> • What do the teachers and students in our school want in the outdoor classroom space? • What is weathering and erosion? How can we prevent it within our outdoor classroom space? • What landscaping and building materials are available? Which withstand weathering and erosion best? 	<p>Author Using students' STEM notebook entries as formative assessments to determine if the design groups have worked collaboratively and effectively to communicate information gathered from individual expert groups.</p>

3. [How Does Soil Form Exit Pass](#) | from CCPS science curriculum - use as formative assessment. See page 16.

Author
This information can also be recorded in students' STEM notebooks rather than on worksheet.

4. Share responses and discuss as a class. Provide access to the same materials, websites, surveys, and other materials used in the expert groups so design groups may revisit the resources as needed to gather additional information or clarify misconceptions. |

Author
BOP 4 - some design groups wanted to revisit the resources to check information or research new questions as they developed.

5. [Weathering and Erosion Stations](#) | based on Discovery Education online resources and CCPS Our Changing Earth curriculum - Students participate in these learning stations to build on their knowledge of weathering and erosion. (See pages 12-14 for directions.)

Author
Notes in students' stem notebooks from these station activities can be used as formative assessment to make sure students are accurately identifying agents of weathering and erosion.

6. [Weathering, Erosion and Deposition flipchart](#) - Students used this teacher made flipchart to analyze photos of real-life situations to determine whether they were caused by weathering, erosion or deposition. The flipchart includes self-checking features so students could work through it at their own pace and use it as a resource while designing their outdoor classroom.

7. [Weathering, Erosion and Deposition Paragraph](#) | this was used as a summative assessment for students. See page 15 for the rubric.

Author
Summative assessment

8. Weathering, Erosion and Deposition [Quiz](#) - this was used as a summative assessment for students. See page 21 for the quiz. Need to insert this.

Author
Summative assessment

Elaborate

1. Revisit the design challenge and review the constraints with the class using the [powerpoint](#).

2. Provide design groups with a copy of the outdoor classroom scaled drawing showing the dimensions that were recorded earlier (see explore #3e).|

Author
BOP 7A

3. Students will need several class periods to brainstorm ideas, discuss possibilities and come to a consensus within their design groups. (See Planning Sheet, pg. 10.)|

Author
BOP 6C - listen to and be receptive to ideas of others

At this point student design groups began further inquiry research. One group wanted to pursue the idea of building a pavilion while another group wanted to find the best material for making tables and conducted a mini-experiment to determine which material provided the smoothest writing surface. Groups needed additional time to question, discuss, research and debate ideas.

Author
SOP 7A – applying technology strategically

4. Use the "Designing our Outdoor Classroom" flipchart so students can see how interior designers create Design Boards to show their plans for redesigning a room. Then show the second half of the flipchart to help students see how landscape architects use Design Boards to show their plans for redesigning outdoor spaces. Students will generate a list of criteria for their own Design Boards including features such as:

Author
SOP 6D – analyze career opportunities

- Scaled drawing of the space
- Symbols to represent seating, display board, path, etc.
- Sketch of the seats, display board, path, other items
- Dimensions labeled
- Color
- Labels

5. Students continue working in their design groups to create a Design Board representing their plans for the outdoor classroom space.

Author
SOP 6B

Evaluate

Inquiry Essential Feature #5 - Learner communicates and justifies explanations.

Author
SOP 4

1. Student design groups present their Design Boards to the class. Classmates will use the rubric to evaluate each group's design and provide constructive feedback.
2. Design groups will meet to put the finishing touches on their boards given the feedback from the class presentations.

3. A panel of specialists will visit the class November 21, 2014 to hear each group's design plan. The panel will include building administrators, the math resource teacher, GT teacher, STEM coordinator, and science supervisor. After viewing all the design boards and talking with the students, the panel will select the design elements that will be used to create the outdoor classroom space at our school.

Author
SOP 6 – another form of collaborating as a STEM team

The Panel of Experts invited to view students' designs are:

(Next to each person's name is the information I shared with students about each expert's role as well student ideas about each expert's interest in our project.)

- Mr. Shumaker - he is a STEM expert so he knows what kind of work/thinking goes into a STEM project like this and wants to see our plans. He will be interested in knowing what kinds of work/learning you had to do ahead of time in order to develop your plan.
- Mrs. Ziegler - as a math resource teacher, she will be interested in hearing our mathematical thinking, like why we chose certain measurements for our seats, tables, etc.
- Mr. Marks & Mr. Ugarte - as construction supervisor and project manager for CCPS these men are responsible for all construction projects happening at schools. They will be involved once construction starts for our outdoor classroom project. They will be thinking about how long it might take to create the design, they will also know which materials are best and what kinds of equipment will be needed to build the things you want in your design.
- Mrs. Koger - a mentor teacher supports classroom teachers - she will be interested to see what 5th graders are capable of doing so she can share this idea with teachers at other schools. She will be interested in knowing what kinds of work/learning you had to do ahead of time in order to develop your plan.
- Mrs. Hoy - she has worked with outdoor school for many years, she knows a lot about outdoor learning spaces and will be interested to see what you've come up with
- Mr. Eisenklam - he is the science supervisor for all elementary schools - he is interested in seeing what 5th grade students have designed. He will be interested in knowing what kinds of work/learning you had to do ahead of time in order to develop your plan.

Extend

1. Once funding has been secured for the project, students will be creating the outdoor classroom space in Spring 2015. A grant application was filed with Lowe's for \$5,000 in September 2014. We have not heard if we've been accepted yet.

2. Invite community members in as guest speakers to discuss landscaping, building materials, and the impact of weathering/erosion with the students.

3. Once the outdoor classroom space is completed, the students can introduce it to the younger students in the school by giving "tours" of the area and highlighting its features.

Author

Due to scheduling, not all of these experts were able to attend the presentations. Students enjoyed having visitors they had not met before, such as Mr. Ugarte. They were surprised at the detailed questions he asked about their designs and the perspective he gave about the reality of such a building project. He gave them insights into the realistic cost of materials and the manpower necessary to implement some of their ambitious designs.

Author

Unfortunately we didn't get the Lowe's grant. We are meeting Feb. 24th to plan which elements of the students' designs we can implement with limited funds.

Author

Due to not receiving the grant, we may need to reach out to community members for donations of materials or labor.

Author

5th graders will be introducing the completed outdoor classroom design to grades K-4. The 5th graders will plan how this will happen once phase one of the outdoor classroom has been built.

Design Brief Spring Garden's Outdoor Classroom

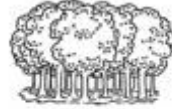


Image Envision - 61771

Scenario:

Two years ago, Spring Garden's fifth grade students designed and planted an afforestation area on our school grounds. The trees they planted are now well established and are thriving. When the trees were planted the students purposefully left a center area unplanted, as an outdoor classroom space.

Design Challenge:

Now it is your turn to be environmental scientists and design Spring Garden's outdoor classroom. While the open, grassy area in our afforestation area is beautiful, it is not conducive to outdoor learning.

You will work in small groups, as a STEM team, to design an outdoor classroom space that can accommodate a class of children while providing group seating and a tool for teachers to use outside, like an indoor chalkboard. A major consideration must be the effect of weathering and erosion on the materials used in your design.

Your group will plan, research and sketch your design before presenting it to a panel of experts in three weeks.

Outdoor Classroom Constraints

The design of your outdoor classroom must:

- Define the path and classroom space
- Provide seating for up to 25 people in a group format
- Provide a display board for teacher/student use
- Be aesthetically pleasing to the natural environment
- Withstand weathering and erosion
- Prevent deposited sediments from going into the drain but allow for the drain to work

Be permanent

Incorporate the use of a new, unique technology (either in the seating or the display board)

Not exceed the \$5,000 budget

Materials:

A. Expert Groups (inquiry research)

- Stakeholder considerations - internet access, paper, pencil, STEM notebooks
- Weathering/Erosion research - internet access, Discovery Education website, STEM notebooks
- Landscaping & Building materials - samples of a variety of materials including Trex, Azek, vinyl, treated lumber, plain lumber; sand paper for testing materials, tubs of water for testing materials, internet access, Lowe's website

B. Design Boards - poster board 24 x 36, scaled map of outdoor classroom, pencils, ruler, colored pencils, markers, STEM notebooks, completed planning sheet, glue sticks

Assessment:

Student work will be assessed using the rubric on the next page (page 8).

Work habits will be assessed using a partner evaluation (see page 9) as well as by teacher observation. The observation and evaluation will determine the rubric rating for each student in this category.

Author

Student Assessment - I used the rubric to assess each design group's work.

Author

Students used this to evaluate members of their design group. Mini-lessons were used throughout this project to help students work collaboratively. Topics like disagreeing respectfully, including all group members, valuing the ideas of others, etc. This helped students be more accountable for their work and encouraged individual accountability.

Outdoor Classroom Design Challenge Rubric

Name(s): _____

+ Evidence on design board and/or model reflects the following:

	3 points	2 points	1 point
Seating	Provides ample seating for at least 25 people in a group format, conducive to an outdoor learning environment. Seating shows exemplary consideration for comfort and durability.	Provides adequate seating for at least 25 people in a group format, conducive to an outdoor learning environment. Seating shows good consideration for comfort and durability.	Provides seating for less than 25 people and/or provides seating but not in a group format conducive to an outdoor learning environment. Seating shows minimal consideration for comfort and durability.
Display Board	A unique type of display board is included in the design to allow for teachers and/or students to write on. Exemplary consideration given to protecting it from weathering/erosion in the selection of materials.	Some type of display board is included in the design to allow for teachers and/or students to write on. Good consideration given to protecting it from weathering/erosion in the selection of materials.	A display board is included in the design to allow for teachers and/or students to write on. Little or no consideration given to protecting it from weathering/erosion in the selection of materials.
Perimeter defined	The perimeter of the path and the outdoor classroom has been clearly delineated, separating it visibly from the afforestation area. All calculations are accurate.	The perimeter of the path and the outdoor classroom has been adequately delineated, separating it somewhat from the afforestation area. All calculations are accurate.	The perimeter of the path and the outdoor classroom has been loosely delineated, separating it visibly from the afforestation area. Calculations contain errors.
Natural environment	The design completely maintains the natural appearance of the environment within the afforestation area.	The design adequately maintains the natural appearance of the environment within the afforestation area.	The design minimally reflects the natural appearance of the environment within the afforestation area.
Weathering & erosion	Materials proposed address the conditions of weathering and erosion present on our school grounds (wind, water, slope of land/gravity). Consideration has been given to effective operation of the storm drain.	Materials proposed address some of the conditions of weathering and erosion present on our school grounds. Consideration has been given to effective operation of the storm drain.	Materials proposed address minimal conditions of weathering and erosion present on our school grounds. Consideration has not been given to effective operation of the storm drain.
Work Habit & Collaboration	The student worked diligently with his/her partner to share the work by being willing to compromise and putting forth outstanding effort throughout the project.	The student worked well with his/her partner to share the work by being willing to compromise and by putting forth good effort most of the time.	The student worked poorly with his/her partner to share the workload by not being willing to compromise and/or by often not putting forth good effort.

----- Author
SOP 7B – analyze the limits, risks and impacts of technology.

----- Author
SOP 7B – analyze the limits, risks and impacts of technology.

----- Author
SOP 2 – Integrate STEM content

----- Author
SOP 2 – Integrate STEM content

----- Author
SOP 2 – Integrate STEM content

----- Author
This portion of the rubric holds students accountable for their contributions to their design team (STEM team). SOP 6B and 6C

Partner Evaluation - Outdoor Classroom Design Challenge

Author

This portion of the rubric holds students accountable for their contributions to their design team (STEM team). SOP 6B and 6C

My name: _____ My partner's name: _____

On a scale of 1 to 3, please rate your partner on each of the following:

	Least		Greatest
Sharing the work	1	2	3
Willing to compromise	1	2	3
Putting forth effort	1	2	3

If you rated your partner as a 1 on either category, please explain below.

Planning Sheet: Outdoor Classroom Design

Names: _____

For each item below, list details to describe the material used, size or dimensions, style/design (what it will look like), etc.

Seating -

Display Board -

Defined path and classroom space -

Other -

Station 1: Virtual Labs

Complete at least one of the following labs on Discovery:

- **Erosion - Here Today, Gone Tomorrow, Levels 1 & 2**
 - As you work through this activity, record your results in your science notebook.

- **Erosion and Deposition**
 - As you work through this activity, make a before and after sketch of each landform in your science notebook. Be sure to label your sketches with the correct type of erosion or deposition (water erosion, wind erosion, deposition by water, deposition by wind).

Station 2: Reading Passages

Read at least 3 of the following passages from Discovery:

- **Baseball Diamond**
- **The Changing Shape of Beaches**
- **Sculptures of Sand and Stone**
- **Moving Cape Hatteras Lighthouse**
- **Land Shaper**

As you read, record notes in your science notebook about erosion, weathering and deposition. Be sure to include real-life examples from the texts.

Station 3: Videos/Images

Read the short text, watch the videos and view the images (photographs) on the **Engage** and **Explore** tabs for the **Erosion and Deposition** lesson from Discovery.

Be sure to record interesting facts and notes in your science notebook.

Station 4: Wind Erosion

Directions:

1. You have a sandy beach in the metal pan. What do you think will happen if a strong wind blows across this beach?
2. Draw a BEFORE picture of the beach in your notebook.
3. Using a straw, take turns blowing from the same direction ACROSS the sand towards the back of the pan. Each person should blow about ten times, until your group reaches a total of 50 blows.
4. Draw an AFTER picture of the beach in your notebook.
5. Answer these questions in your notebook:
 - What are the effects of wind erosion on this beach?
 - How was deposition shown in this activity?

Weathering, Erosion, Deposition Paragraph Rubric

Name _____

Date _____

3	2	1	0
The lead sentence completely <u>grabs the</u> reader's attention.	The lead sentence grabs the reader.	A lead sentence begins the paragraph.	There is no lead sentence.
The writer defines weathering and clearly explains several examples.	The writer defines weathering and provides an example or two, without explanation or detail.	The writer defines weathering OR gives an example.	The writer does not define weathering and does not provide an example.
The writer defines erosion and clearly explains several examples.	The writer defines erosion and provides an example or two, without explanation or detail.	The writer defines erosion OR gives an example.	The writer does not define erosion and does not provide an example.
The writer defines deposition and clearly explains several examples.	The writer defines deposition and provides an example or two, without explanation or detail.	The writer defines deposition OR gives an example.	The writer does not define deposition and does not provide an example.
The writer has a strong closing sentence and the reader is not left wondering if the paragraph is finished.	The writer has a closing sentence and the reader is not left wondering if the paragraph is finished.	The writer has a closing sentence.	The writer does not have a <u>closing</u> sentence.
The writer uses correct capitalization, punctuation, spelling and sentence structure throughout the paragraph.	The writer uses correct capitalization, punctuation, spelling and sentence structure in most of the paragraph.	There are some errors with capitalization, punctuation, spelling and sentence structure throughout the paragraph.	There are so many errors with capitalization, punctuation, spelling and sentence structure that it is difficult to make sense of the content.

Today you explored how weathering and erosion work together to change the surface of the Earth.

- You observed water, in the form of rain, weathering (breaking up) rocks and eroding (carrying) them away. This changed the surface of the hillside.
- You saw sandpaper weather a pencil. This changed the surface of the pencil.
- You also saw how salt weathered and eroded a piece of sidewalk chalk changing the size of the chalk.

Soil is made up of tiny pieces of rock, minerals and decayed plant and animal matter. It makes up most of the surface of our Earth.

- Based on the observations you made today and your knowledge of weathering and erosion, explain how soil is created.



Unit: Our Changing Earth
Lesson Title: Weathering and Erosion - Wind

Wind Lab Sheet

Wind Lab Sheet



1. **Prediction:** What do you think will happen if a strong wind storm blows across the beach?

2. **Observation:** What happened when the “wind” blew across the beach? In the space below, draw and describe what you saw.

3. Which process (weathering or erosion) was being demonstrated by blowing the sand? Justify your response.

4. How can the wind cause weathering?

5. How can the wind cause erosion?

6. What causes a sand dune to form?

7. Explain one way that farmers can prevent wind erosion. Why does this work?

Water Lab Sheet

1. **Prediction:** What do you think will happen to the sand when a wave hits the shoreline?

2. **Recording:** Describe what happened as a result of the wave reaching the shoreline of the beach.

3. Which process (weathering or erosion) was being demonstrated by a wave hitting the shoreline? Justify your response.

4. How does water cause weathering and erosion?

5. How can houses that were once near the ocean end up being in the ocean?

6. Explain how waves can weather rocks that are near the ocean.

7. Erosion causes the formation of deltas. Describe a delta and how it forms.

APPENDIX L

Sample Reflection for Key Assessment 3

My lesson planning has developed and evolved as a result of my studies within the McDaniel Elementary STEM Instructional Leadership program. In this paper I will reflect on my lesson planning and address how I used the Maryland STEM Standards of Practice as well as formative and summative assessments to improve my lesson planning and inform instruction. As a result of my work in this cohort, I have learned to plan and implement transdisciplinary, 7E lessons to engage my students in authentic, real-world problems while applying integrated STEM content and using behaviors based on the Maryland STEM Standards of Practice. I will also identify areas of my lesson plan which could be strengthened based on what I've learned about the indicators of the STEM standards.

Rubric indicator #1:

Lesson engages students in exploring and developing understanding of STEM content and provides them with opportunities to apply STEM content and practices to solve authentic problems.

My 7E Outdoor Classroom lesson plan evolved from the authentic problem of the outdoor classroom that needed to be designed as a follow up to the afforestation project completed by fifth graders two years ago. When the trees were originally planted, we had left an open area in the center to be used as an outdoor classroom for observation and nature study experiences. Now that the trees are established and thriving the time was right for creating the outdoor classroom space.

In order to prepare students for college and career readiness, I know that not only do I need to provide authentic integration of STEM content but I also need to incorporate the use of STEM Standards of Practice. According to the Maryland State Department of Education's website, "STEM Standards of Practice guide STEM instruction by defining the combination of behaviors, integrated with STEM content, which is expected of a proficient STEM student." When planning for this 7E lesson, I purposefully planned for the following STEM Standards of Practice:

- #2 – Integrate Science, Technology, Engineering, and Mathematics Content
- #4 – Engage in Inquiry
- #6 – Collaborate as a STEM Team
- #7 – Apply Technology Strategically

Students were presented with the authentic design challenge of creating an outdoor classroom and were immediately engaged and interested in creating a useable learning environment within the afforestation area. This design challenge provided an authentic context for STEM content (**STEM Standard #2**) including:

Science – CCPS Science Curriculum -

- Recognize and explain how physical weathering and erosion cause changes in the Earth's surface.
- Describe how weathering wears down Earth's surface: Water, Ice, wind
- Cite evidence to show that erosion shapes and reshapes the Earth's surface as it moves Earth's materials from one location to another (water, ice, wind)
- Cite examples that demonstrate how the natural agents of wind, water and ice produce slow changes on the Earth's surface.
- Describe ways that the following processes contribute to changes always occurring to the Earth's surface: erosion, transportation, deposit

Technology –

- **SOP 7 – Apply Technology Strategically**
 - A. Identify and understand technologies needed to develop solutions to problems or construct answers to complex questions.
 - B. Analyze the limits, risks and impacts of technology
 - C. Engage in responsible/ethical use of technology.
 - D. Improve or create new technologies that extend human capability.

Engineering – Next Generation Science Standards: Scientific and Engineering Practices #8 – Obtaining, Evaluating and Communicating Information

- Express ideas orally and in writing, with the use of tables, graphs, drawings or models
- By engaging in extended discussions with peers
- Communicate the advantages of their designs persuasively
- Derive meaning from colleagues' texts
- Evaluate information and apply it usefully

Mathematics – Common Core State Standards

- **5.NBT.7.** Add, subtract, multiply, and divide decimals to hundredths.
- **5.NBT.5** Fluently multiply multi-digit whole numbers using the standard algorithm.
- **4.MD.3** Apply the area formulas for rectangles in real-world and mathematical problems. For example, find the width of a rectangular room given the area of the flooring and the length, by viewing the area formula as a multiplication equation with an unknown factor.

The lesson includes opportunities for students to engage in the inquiry necessary to answer their own questions about complex questions, global issues and/or real world challenges.

In the elicit stage of this lesson, I began showing students how their questions and ideas were valued by recording these on a What we Know/What we Need to Know chart. I used ideas and questions from this step as a form of pre-assessment to determine my students' prior knowledge about topics such as weathering, erosion, outdoor learning spaces, as well as the design process. Within the explore stage of this lesson, students worked in inquiry groups to

research specific features of the design challenge. These groups developed their own questions related to the overall design challenge to guide their work. Examples of each group's guiding questions can be found on page 2 of my lesson.

As the authors state in the article *Shifting to an Inquiry-Based Experience* (Corder), it is important for teachers to “present opportunities for students to ask and refine their own questions” in order to for students to value and make sense of their own learning. This article also recommends that teachers allow students to record their results and data in their own way rather than using a teacher-made data table or chart. While it is much easier to make multiple copies of a worksheet or data table from the provided curriculum, I have found that by allowing my students the opportunity to record their learning in a way that makes sense to them, they have been freed to explore without restrictions. Of course students have also needed guidance along the way so that they would have some evidence of their learning documented in their notebooks from which they could pull during classroom discussions. But it has been powerful to see my students realize the need for keeping organized notes, observations and data over the course of the school year.

The learning experience is driven by students making connections between disciplinary content knowledge and practices.

In planning for this real-world design challenge, I began with standards from the 5th grade science curriculum, then considered the natural math applications my students would need as they worked through the design process. When using STEM-centric planning, I've learned not to force curricular connections, but rather to make use of naturally occurring applications. Therefore, it's perfectly fine to draw on math skills from the previous year's curriculum or units taught earlier in the school rather than trying to incorporate the current math unit's skills within a design challenge. In the case of the outdoor classroom design project, my students needed to make use of their knowledge of calculating area and perimeter in order to determine the size of the outdoor classroom space as well as the amount of space taken up by their design elements such as paths, walkways, ground coverings, seating, or pavilions. My students also needed to work within a budget so they were required to calculate the cost of materials used and be sure the cost of their project did not exceed the given budget. Additionally, I have found that the engineering and technology content skills are naturally embedded within authentic design challenges. For this project, students used the engineering design process to identify the problem, design a solution, evaluate their ideas, redesign or revise and implement their plan. While technological skills included the use of appropriate tools to solve problems during the design challenge as well as evaluating appropriate technologies. In my experience, the key to effective STEM-centric planning is to incorporate natural curricular connections centered on an authentic, real-world problem.

While the planning process involved in this 7E lesson required me to think through connections between disciplinary content knowledge and practices, I feel that the learning

experience was also student driven. This was especially evident once student design groups began planning their outdoor classroom space in earnest. As I purposefully stepped back and watched student groups work, while facilitating their progress, I saw groups solving problems using curricular connections such as determining the size of seats or benches, the height of decking, the types of ground cover to use, evaluating the effectiveness of different building materials, using tools to measure familiar objects in order to plan the size of new structures and much more. Had I planned mini-lessons suggesting similar strategies, I feel I would have hindered my students' motivation and creativity by inadvertently suggesting that my way was the best way to proceed.

The lesson plan suggests how students work in formally structured teams with clearly defined expectations for individual and team accountability, but allows for students to take ownership in how their work is planned and structured. The collaborative group functions in a similar manner to a real-world collaborative team.

During the explore stage of the lesson, students were able to self-select their design groups of 3-4 students. Students were also regrouped into inquiry groups in order to divide up the research work necessary before designing could begin within design groups. On page 3 of my lesson, I listed the general instructions in black that I used when introducing the purpose of each inquiry group. In red you will see the questions each group developed to guide their research. Each inquiry group was made up of 6-8 students so I found it to be valuable to help structure how each group would go about their research work. Students chose to take turns recording (taking notes in stem notebooks) or researching (actually touching the computer to access online resources) while partnering up within their inquiry group. So within each inquiry group, there were 3 or 4 teams doing similar work and gathering similar information which was then compiled in order to be shared with design groups later. While I did not assign formal roles to group members, I did find that I needed to provide helpful suggestions to move each group forward, which I felt allowed my students more ownership and choice in their work. The partner evaluation on page 9 of my lesson provided the individual accountability necessary when students work in small groups while team accountability was built in to the rubric on page 8 of the lesson. Team accountability focused on content knowledge while individual accountability focused on work habits and behaviors. In reflection, I feel that I could certainly strengthen this component of my lesson by using video clips of stem careers to show students how collaborative groups function in the real-world. A great resource would also have been Kid President's video: A Pep Talk about Leadership and Teamwork (<https://www.youtube.com/watch?v=wzF23qI3Djw>) which I had forgotten about until reflecting on this lesson! I'm sure other resources are also available. It is particularly important for students to understand that collaboration is a real-life skill they will use in their high school, college and career experiences.

The lesson plan describes learning experiences where students select technology tools and use them creatively to develop solutions to problems and/or construct answers to complex questions.

As students worked within their design groups to plan their outdoor classroom, they made use of tools such as rulers, yardsticks, meter sticks, centimeter grid paper, square foot floor tiles, and even classroom chairs and desks. I enjoyed watching the students creatively find ways to answer their own questions such as, “How high and wide should the seats be?” Some design groups measured the seats of classroom chairs while others sat on the square foot classroom floor tiles, then measure the space taken up by their gluteus maximus! ☺ Still other groups considered the proper height of benches or stools by measuring the length of student legs and adult legs. As design groups worked to determine appropriate ground covering for their outdoor classroom space, they used technology to recreate classroom investigations in which we were determining which building material would best withstand weathering or erosion. Student groups used sand paper, running water and even their own shoes to try to weather materials. One forward thinking group used scraps of the building materials to investigate which would provide the smoothest writing surface for the top of a picnic table. The tools they used for this particular investigation were paper and pencil in addition to the sample building materials. These are just some of the examples of the many ways my students creatively used technology to develop solutions and answer complex questions during the design process. When I first started planning 7E lessons, I tried to think through every possible scenario and plan for all possibilities. I found this to be exhausting! In time I gained enough confidence to realize that I needn’t consider every possibility. I need to do enough planning to ensure that my students have the prerequisite skills but then give them the freedom to take charge of their own learning within the design challenge’s constraints. I am constantly amazed at my students’ creativity and enthusiasm when I let them have the productive struggle just like real-life STEM teams.

The lesson plan describes learning experiences that provide students with opportunities to develop science and engineering practices as they seek answers to thoughtful questions they have developed, define complex problems and develop and use models, and plan and carry out investigations.

This 7E lesson provided students with multiple opportunities to develop the Next Generation Scientific and Engineering Practices, including:

1. Asking Questions and Defining Problems – evident in the elicit and explore stages of the lesson as mentioned above
3. Planning and Carrying Out Investigations – students carried out investigations to determine the best materials for withstanding weathering and erosion

5. Using Mathematics and Conceptual Thinking – students used math to calculate the outdoor classroom’s area and perimeter, as well as the dimensions of their design elements (seating, path/walkway/ground cover, display board, etc)
6. Constructing Explanations and Designing Solutions – students created a scaled drawing to reflect their outdoor classroom design and incorporated this scaled drawing with a design board which explained the features of their design
8. Obtaining, Evaluating and Communicating Information – expert groups gathered applicable research and communicated that information with their design groups during the explore stage of this lesson, design groups shared their scaled drawing and design boards with a panel of STEM experts during the evaluate stage of the lesson

Rubric Indicator #2:

Lesson requires students to use STEM content and practices to extend their learning to new problems or situations.

Within the lesson, students are asked to improve or create a new technology to extend human capability.

A critical component of this design challenge was that students needed to incorporate a unique technology within their outdoor classroom design. I gave the students the suggestion of doing that within their seating design or display board design. The constraints stated that students needed to provide seating for approximately 25 students (one class) as well as providing a method for displaying/recording student ideas – such as a board that could be written on or used to tack up paper to record ideas while classes use the outdoor classroom space. Students were challenged to do more than just find a ready-made seat or board to use in their design. This component of the lesson stretched students’ creativity while allowing them to apply what they’d learned about how building materials withstand weathering and erosion conditions. Some design groups used natural elements such as logs, but planned to cover them with plastic seat cushions to hinder decomposition. Other design groups planned to build a flat surface board using treated lumber and then adding a roll-up weather protection shield to hinder the effects of weathering. Students were clearly making use of what they’d learned about the causes of weathering and erosion while demonstrating their creative problem solving abilities to improve and create new technologies, thereby extending human capabilities.

Within the lesson, students are asked to systematically analyze the limits, risks, and impacts of technology and to defend their findings.

As part of this design challenge, students were given the constraint that their design must “be aesthetically pleasing to the natural environment.” As students generated ideas and possible design solutions, they often asked each other, “Will that be aesthetically pleasing to the natural environment?” Of course, I had to explain the meaning of aesthetics, but students were quickly

able to understand this concept. We spent a lot of time discussing this and considering the function of the seating versus its aesthetics. For example, several design groups planned to build structures which would provide shelter for the seating and display board, but would obviously obstruct the view of the natural environment. As groups evaluated their designs, improvements were made to redesign these structures using open walls, plexiglass ceilings and natural stone foundations. Students were analyzing the limits of the technology they had designed in order to make sure it did not detract from the natural environment of the afforestation area. As part of this analysis I found that we also had to revisit the purpose for the outdoor classroom: to provide an outdoor learning environment where students could observe and make use of natural settings within our school yard. With this purpose in mind students were able to consider and discuss the impacts of their technological designs.

The lesson requires students to effectively communicate their understanding of STEM content by developing an evidence-based argument that addresses multiple perspectives of an issue or problem.

One way students considered multiple perspectives of the outdoor classroom project was within the Stakeholder Consideration expert group. They gathered information through teacher/staff surveys which design groups would use as they developed their outdoor classroom designs. Feedback from classroom teachers included the desire to have a place to sit as a whole class, a defined path and a place to set artifacts (like a table). Other stakeholders wanted a place to store science materials like insect nets, bug containers, and magnifying lenses. Feedback from the building supervisor asked us to consider the ease of maintaining the area, such as mowing and weeding.

Another way students considered multiple perspectives was evident as they prepared for their presentations to the panel STEM experts, see page 5 of the lesson plan. Students worked diligently to design a useful outdoor learning space, while considering environmentally friendly and structurally sound designs. One group really wanted to impress the STEM specialists and outdoor school staff by adding a composting toilet to their outdoor classroom!

Besides creating their design boards and scaled drawings, students also wrote an introduction to their outdoor classroom in which they highlighted unique aspects of its design meant to persuade the panel of experts of its qualifications. As a result students worked to effectively communicate the features of their design with an evidence-based argument addressing multiple stakeholder perspectives.

The lesson plan includes engaging, open-ended pre-assessment of students' prior understanding of content knowledge in the context of a real situation.

During the elicit stage of the 7E lesson, I assessed my students' prior knowledge of content knowledge within the context of the outdoor classroom design challenge as I recorded

students' ideas using the What we Know/What we Need to Know chart. This method posed open-ended questions to the class, allowed students to discuss the questions with others and recorded their ideas for future reference. It also got the students immediately engaged in the design challenge by thinking about what they already knew that would be helpful and what they needed to know in order to proceed with the challenge.

Rubric Indicator #3:

Lesson comprehensively evaluates student progress (including pre, formative and summative assessment).

The lesson plan is designed to offer students multiple opportunities to demonstrate their understanding of the STEM content by recalling and applying concepts and providing them an opportunity to discuss how their learning evolved.

Multiple opportunities for students to demonstrate their understanding of STEM content were incorporated into this 7E lesson. During the work in expert groups, students were gathering initial information and research for their design groups. At this time, students had the opportunity to informally discuss and clarify new learning. Within design groups, students had the opportunity to apply what they'd learned about weathering and erosion more formally as they considered the types of building materials to use within their outdoor classroom design. Formative assessments were used to track individual student achievement as well as anecdotal notes gathered during design group work sessions. Individual assessments included the use of teacher made quizzes and worksheets from the 5th grade science curriculum. I've added these to the 7E lesson plan to show where and how I used them within the development of the lesson. The design challenge itself was the summative assessment for students which was scored using the rubric on page 9 of the lesson plan.

Pre-Assessment used at the beginning of the 7E lesson:

- Student responses What we Know/What we Need to Know chart
- Student generated questions during initial meeting with expert groups

Formative assessments used within the 7E lesson:

- STEM notebook notes from Weathering and Erosion station activities
- STEM notebook notes from the expert group research work sessions
- STEM notebook notes from the design group work sessions
- Anecdotal notes gathered from both the expert and design group work sessions
- CCPS science curriculum worksheets – In my classroom I use these curricular worksheets to guide classroom experiences and discussions. The actual worksheet from the curriculum is modified and students record their work in their STEM notebooks to show their thinking and learning.
 - How Does Soil Form Exit Ticket

- Weathering and Erosion Wind Lab
- Weathering and Erosion Water Lab

Summative assessments used within the 7E lesson:

- Weathering, Erosion and Deposition Paragraph – rubric within lesson plan
- Weathering, Erosion and Deposition quiz
- Outdoor Classroom Design Challenge – rubric within lesson plan

STEM notebooks are used to inculcate habits of mind that permit students to demonstrate a comprehensive understanding of STEM content through evidence-based arguments.

In *Five Good Reasons to Use Science Notebooks*, the authors state that the use of notebooks is “a tool for every student to use to construct his or her own conceptual understandings” (Gilbert). Throughout this 7E lesson my students have used their STEM notebooks to record their questions, ideas, new learning, vocabulary, observation and data as well as conclusions. Student notebooks are used as a tool for classroom discussion and as a way for students to document and track their learning over time. Students are regularly asked to find evidence in their STEM notebooks to support their ideas and explanations. However, I feel that I could strengthen my students’ awareness of the STEM standards of practice/habits of mind by bringing these to the forefront of each day’s work. For example, I plan to include STEM standards within the daily objectives written on the classroom chalkboard in order to make students aware of the behaviors they are using as they are engaging in STEM work. Therefore, a possible daily objective would be, “Today in science we will collaborate as a STEM team by listening to and being receptive of others as we model the effects of gravity on everyday objects.” Through professional development sessions with our school’s math resource teacher I’ve learned to write specific daily math objectives using the Math Standards of Practice. At first I balked at the idea thinking that the language was awkward for students. However, I’ve been pleasantly surprised at how the students have taken to the new format and have begun using the language of the math practices during class discussions. I feel that a similar approach would be just as valuable by purposefully incorporating the STEM Standards into my daily science objectives. When these standards are written on the board for all to see, they are valued and addressed rather than being “hidden” in a teacher’s plan book. It then becomes very easy for me to use the language of the STEM standards during class discussion or closure by asking specific questions such as:

- “How did demonstrate listening to others today during your work modeling the effects of gravity?”
- “How did you demonstrate being receptive to others today during your work modeling the effects of gravity?”
- “How did you collaborate as a STEM team today?”

Student responses to these questions could be recorded in individual STEM notebooks as well as on a classroom anchor chart.

Rubric Indicator #4:

The narrative describes the candidate’s knowledge and application of STEM-centric planning.

Reflection shows substantial evidence of synthesis of STEM Standards of Practice 2, 4, 6 and 7 presented in the STEM Instructional Leadership Program.

The reflection on this lesson plan is guided by critical insights developed throughout the STEM Instructional Leader Program.

I believe that my reflection on the Outdoor Classroom 7E lesson has provided substantial evidence of the synthesis of STEM Standards of Practice 2: Integrate Science, Technology, Mathematics and Engineering Content, 4: Engage in Inquiry, 6: Collaborate as a STEM Team and 7: Apply Technology Strategically, as presented in the STEM Instructional Leadership Program through McDaniel College. While I feel that my lesson planning and teaching is always evolving, I have gained confidence and valuable STEM resources from my participation in the STEM Instructional Leadership Program. I no longer rely strictly on “cookbook” labs or scripted lesson plans provided by others. Now I am able to identify a science standard, determine my students’ needs and plan accordingly while allowing my students the autonomy to demonstrate their learning through a variety of methods, including by tackling real-world problem solving and design challenges which would have been far outside my comfort zone a few years ago!

Works Cited

Corder, G., & Slykhuis, J. (2011). Shifting to an Inquiry-Based Experience. *Science and Children*, 60-63.

Gilbert, J., & Kotelman, M. (2005). Five Good Reasons to Use Science Notebooks. *Science and Children*, 28-32.