PRESERVICE TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE OUTCOMES ASSOCIATED WITH A K-12 DINOSAUR LEARNING PROGRESSION

A Dissertation

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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May 2018

Major Subject: Curriculum & Instruction

ABSTRACT

Curriculum developments guiding science in schools have evolved from textbook-based teaching to integrated content approaches focusing on the nature of science. The *Next Generation Science Standards* (NGSS) reflect a reformed and authentic science pedagogy in the most innovative manner for any curriculum guide to date. Learning progressions (LPs) are a current innovation changing science education that support NGSS goals. LPs provide a guide for aligning mastery of science concepts over time and integrate topics between different concentrations of science.

The preparation of science teachers has relied heavily upon traditional science courses at the collegiate level. Conventionally, preservice teachers develop pedagogical practices through education coursework and field placements in K-12 schools. To fully ensure the development of scientific literate teachers, preservice science teacher education needs to focus on pedagogical content knowledge (PCK). Preservice teachers need to be able to teach beyond the explicitly stated examples provided in curriculum frameworks and meet the interests of their future students.

In this three-article dissertation, I explored the development and use of a LP in preservice teacher education. In the first article, I outlined a new methodology for creating valid LPs by utilizing expert interviews and documents for triangulation. The LP I built used dinosaurs, the number one science interest of students entering school, as the thematic vehicle for delivery of Earth and life science concepts. In the second and third articles, I targeted the developed dinosaur LP as an intervention for meeting the needs of enhancing preservice teacher PCK. In the second article, I used concepts maps to measure the conceptual knowledge gains of preservice teachers. The third article reported results of preservice teachers' pedagogy transformations in the form of 5E lesson plans.

Results suggested LPs can increase preservice teacher PCK in targeted conceptual areas and pedagogy, as reflected in concept maps and lesson plans. Significant differences existed between individual and group-developed concept maps, indicating distributed cognition may increase PCK development. Examination of pre- and post-intervention lesson plans revealed significant gains in pedagogical methods for the overall construction and subcomponents of lesson plans. These results supported the use of LPs as interventions impacting preservice teacher PCK.

DEDICATION

I would like to dedicate this dissertation to my family. To my parents, Leslie and Donald Lyons, I would not have been able to pursue higher education without your support. Whether it was educational, financial or emotional, the support you give to me has been the reason I have been able to chase my dreams. Mom and Dad, from my Bachelor of Science at Texas A&M University and my Master of Education at Sam Houston State University to this Doctor of Philosophy at Texas A&M University, you have always been my inspiration. The infusion of dinosaurs into this dissertation stems from the encouragement provided by both of you to pursue my interests in science at a young age. The focus on teaching in this study can be traced back to the importance on helping and serving others exemplified by both of you. To my wife, Maria Lyons, you have been there for all the late nights, brainstorming of ideas and my experiences during graduate school. On our first date, I told you I wanted to go back to school and you were supportive of that dream from the beginning. Your encouragement throughout this process was exceptionally valuable. The three of you are the most loving support team that any person could ask for during a process as strenuous as completing a Doctor of Philosophy program. To my daughter, Laurel Jane Lyons, at the time of writing this we are still waiting for your arrival. You are the reason I will continue to pursue this career and my motivation for the future. I love you all.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Carol L. Stuessy, and my committee members, Dr. Lynn M. Burlbaw, Dr. Julie Singleton, and Dr. Christopher M. Quick, for their guidance and support throughout the course of this research. Dr. Stuessy, you gave me an opportunity to pursue this degree and your direction has been invaluable. Our three-hour conversation during my interview for the program, the first trip to School Science and Mathematics Association conference, the countless sessions of mentorship at the kitchen table and freedom to pursue my own research agenda will never be forgotten. Dr. Burlbaw, the initial study that led to this dissertation came from an inquiry into the history of curriculum that you supported. With you, I experienced my first conference presentation, an induction into Kappa Delta Pi and many other events during graduate school. Dr. Singleton, thank you for your continued guidance for teaching at the collegiate level. You gave me the autonomy to try new methods in my teaching, many of which led to this study. Dr. Quick, this all began with you. I was lucky to do a research internship with you after my first year of teaching high school. That experience sparked my interest in research and led to my pursuit of this degree.

A special thanks to everyone that helped with this research study. Thank you, Dr. Kenneth Fleming and Dr. Dane Bozeman for helping with coding to set up for data analysis. Dr. Thomas Holtz, Dr. Louis Nadelson, Dr. Scott Sampson, and Dr. Molly Weinburgh deserve special recognition for offering their insights during interviews with me to establish the framework for this dissertation.

Along the course of this journey, many other faculty members in the Department of Teaching, Learning, and Culture impacted my education. Dr. Hersh Waxman, thank you for giving me the opportunity to be a research assistant with you in the Education Research Center. My abilities to complete this study are attributed to your teachings and guidance. Dr. Larry Kelly, our outings to museums, ballgames, and fun times in the science education classroom made the graduate experience fun. Thank you for believing in the idea of dinosaurs in the classroom and sharing in my love of these prehistoric beasts. Dr. Jacqueline Stillisano, thank you for the direction of building data sets, conducting research, and other experiences you provided in the Education Research Center. Senior Methods faculty, thank you for the support during my initial teaching assignment and throughout my four years teaching in the department. Particularly, thank you Drs. Robin Rackley, Diane Goldsby, Janet Hammer, and Ms. Karee Griffith during my senior methods teaching assignments. Each of you gave advice and believed in my ability to serve our preservice teachers with my instruction.

To the staff of the Department of Teaching, Learning, and Culture, I thank each of you for all you did for me during this time. A special thanks to Tammy Reynolds. Thank you for the incalculable times I interrupted your day for help with any of the multitude of matters that arise during graduate school and teaching. Kelly Freeman, your work behind the scenes to make sure that our assistantships and finances in graduate school are taken care of is greatly appreciated. Andrea Caldwell-Williams, thank you for helping with travel arrangements and funding reimbursements to present my research over the past five years. Joan Davison, thank you for all the times I needed to order books for a class and reserve a room for research. Your help with was essential during my time as president of the Graduate Student Association. Kerri Smith, you were the cornerstone of advising and your help provided for a very enjoyable and productive experience during graduate school.

I would like to give a special thanks to a few extraordinary undergraduates at Texas A&M University. In January of 2016, I embarked on establishing an undergraduate research team in science education. I would mentor a few special students in research. Marcus Lys, Diego Regalado, and Trey Reeves, thank you for working with your former high school teacher, as it made the research experience that much more special. Tanis Scott, I will never forget the transformation and ownership of scientific inquiry you took from the research experience into your classroom, including co-presenting with me to your agriculture education cohort. Brie Snider, you were the only undergraduate to interview for the team and have been to more conferences with me than any other member. Your fun, whimsy and spirit brought a special element to our team. To Katie Thomson and Alyssa Bourquein, thank you for stepping outside of your comfort zone and pursuing research in science education. Katie, you have a gift for research and a made me a better researcher. Alyssa, thank you for joining the team and transforming our research into your own teaching philosophy. Also, to my undergraduate students at Texas A&M University, your passion for teaching was a driving factor in focusing my research on preservice teacher education.

An acknowledgement section would be incomplete without a special recognition of Navasota High School. A special thanks to Amy Jarvis. I remember you asking to speak with me during the last day of my student teaching placement. You would offer me a job to teach biology. Without your faith in my ability to teach, I am not sure I would have pursued this degree. Thank you, Caley Lee, for the mentorship you provided to me during my student teaching and continued support over the years. To all my Rattlers, thank you for inspiring your teacher. Usually it is our job to inspire students, but the Rattlers of NHS motivated me to teach with purpose and passion. Thank you to all my former students, I was able to become the teacher I am today because of you. A special thanks to all the members of my UIL Math and Science team. We went from last place in the district to being perennial district champions and state competitors. Your dedication is my most cherished memory of teaching high school. Thank you to all the faculty and staff members at Navasota that made my high school teaching experience special, especially: Keith Brown, Daniel Posey, Rebecca Hill, Ali Coker, Justin Barrett, Darcie Crumpacker, Nancy Bouliane, Sonny Soltis, Kristi Ramsey, Derek Bowman, Kim Meschke, Cornelia Wilson, Michele Harrington, and Ofelia Ruiz.

Finally, thanks to my family. Mom and Dad, you made all of this possible and your support from preschool through a doctorate is the only reason I am able to thank everyone I mentioned above. The two of you dedicated your lives to raising and loving me, which allowed me to pursue my interests and passions. To my beautiful wife, Maria, you were the final piece to the puzzle. When we met, I was a high school biology teacher that eventually wanted to go back to pursue a doctorate. Your love for me made any struggle during graduate school easy to overcome. I cannot thank the three of you enough for your support throughout this five-year journey.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supported by a dissertation committee consisting of Professors Carol L. Stuessy, Lynn M. Burlbaw, and Julie Singleton of the Department of Teaching, Learning and Culture and Professor Christopher M. Quick of the Department of Veterinary Physiology and Pharmacology.

Dr. Carol Stuessy, Dr. Kenneth Fleming, and Dr. Dane Bozeman all assisted with the development and coding processes required for the completion of this study. Katie Thomson, Brie Snider, and Alyssa Bourquein all aided in the development of grade specific learning activities for the learning progression. Dr. Carol Stuessy was a big contributor for the editing and revising during the writing process. All other work conducted for the dissertation was completed independently by myself.

Funding Sources

My primary funding for graduate school was provided through a teaching assistantship with the Department of Teaching, Learning, and Culture. Additional funds for graduate studies were provided through the Education Research Center under the direction of Professor Hersh C. Waxman and the College of Veterinary Medicine and Biomedical Sciences for program design and research with Professor Christopher M. Quick. Travel funds to present research associated with this dissertation were provided by the College of Education and Human Development, the Office of Graduate and Professional Studies, and the Department of Teaching, Learning, and Culture.

NOMENCLATURE

LP	Learning Progression
PCK	Pedagogical Content Knowledge
SCLE	Student-Centered Learning Environment
K-12	Kindergarten through Twelfth Grade

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CHAPTER I

INTRODUCTION

Science Education of Today

Learning science should engage students in high-interest areas and reflect authentic science practices. Scripted science lessons in classrooms have reduced the interwoven relationships of science concepts. There are many topics that have the ability to engage students and expand their conceptual understanding of science. For example, dinosaurs are not explicitly stated in science standards, but possess the versatility to teach science in a student-centered and interdisciplinary manner. The possibility to adapt curricula to meet high-interest topics dissolves unless teachers have the ability to utilize reformed science pedagogical methods supported by accurate science content.

National Standards in Science Education

The launching of Sputnik by the Soviet Union rushed in an era of science education advancement in the United States (Rutherford, 1997). After this period of scientific advancement and the space-race era concluded, the focus on science curriculum turned towards structure of what to teach. *Science for All Americans* was released in 1989 and served as the precursor to the current Science, Technology, Engineering and Mathematics (STEM) movement (Rutherford & Ahlgren, 1991). This lead the way for the *Benchmarks for Science Literacy, Project 2061*, which was one of the first successful attempt to establish a national standard for science education standards (American Association for the Advancement Science [AAAS], 1993). Following in 1996, the *National Science Education Standards* (NSES), created an environment in science education that became confined within a scripted framework (National Research Council [NRC], 1996). Trading off reliability and validity of the standards for flexibility and authenticity to the nature of science, the NSES became increasingly standardized. Currently, the *Next Generation Science Standards* (NGSS), attempt to provide cross-cutting concepts, engineering design processes, inquiry practices, reflect the nature of science, while coordinating with state and Common-core standards (Bybee, 2014; NGSS Leads States, 2013). This current effort includes the recognition of learning progressions (LPs) with a supplemental building vertically aligned through grade levels. National standards for science education began rigidly focused on what to teach. Currently, the shift is towards a curriculum that progresses students' learning and is integrated throughout the curriculum.

Student-Centered Learning Environments for 21st Century Learners

Today's students need to be motivated to learn in ways that were not present in the previous century. 21st century learners "often express a preference for doing rather than listening" (Lombardi, 2007, p. 2). This is mirrors the theoretical foundations of student-centered learning environments (SCLEs) (Land & Hannafin, 2000) and activity theory (Jonassen, 2000). Authentic SCLEs create spaces for students to learn through doing inquiry, problem or activity driven learning. Authentic learning needed for 21st century learners must be relevant, situational, create collaborative opportunities, create time for reflection, incorporate multiple disciplines, and allow for multiple perspectives based upon various inputs of data (Lombardi, 2007). The school science laboratory continues to be an important fixture in science classrooms. While a physical lab does not need to exist, the practices of science skills, and inquiries based in the nature of science do need to be practiced and implemented in all science classrooms to help students develop conceptual understandings (Hoffstein & Lunetta, 2003).

Poorly designed environments can hinder student learning and engagement. "Cook-book" labs, omitting assessment of skills in high stakes testing, and limiting resources in the classroom create potential hurdles that the 21st century learner may not be able to overcome. To create authentic SCLEs, students must be able to approach science so that cognitive resources are connecting with prior knowledge, laboratory skills and build ideas conceptually (Etkitna et al, 2010). Science for a child in K-12 today needs to reflect authentic science, be student-centered, create a reason to learn, and build knowledge conceptually.

Teaching in the 21st Century

Previous research (Tobin & Gallagher, 1987; Gardiner & Farrangher, 1997) has found that teachers may value the nature of science but do not often exhibit teaching practices that promote hands-on learning through doing. Student-centered instruction is not a new practice, nor a new issue, as teachers tend believe that content knowledge is more important in relation to science practices and skills (Hofstein & Lunetta, 2003). However, especially in science, teacher education emphasizes learning core conceptual knowledge about various science topics in traditional lecture halls (Lederman, Gess-Newsome, & Katz, 1994). This is a poor model and a change is needed. Some programs in teacher education offer hybrid, content-based science education courses that stress science content through pedagogy (Lyons, et al., 2015). By putting the learning in the hands of the students with facilitation by the teacher, intrinsic motivation can be increased which can possibly lead to a more motivated student (Hidi & Harackiewicz, 2000).

Science Literacy

As a follow up to *Science for All Americans (SFAA)*, the *Benchmarks for Science Literacy* (1993) aimed to recommend what all students should know to help them become scientifically literate adults. This publication was aimed to guide science reform and integrate mathematics and technology into science education. One goal of the Project 2061 was for the *Benchmarks for Science Literacy* to reduce the massive amount of information that other curricula suggested to be covered. This led to a more integrated approach with scientific themes and concepts at the forefront instead of detailed facts. This integrated conceptual approach was theorized to lead to higher student understanding. *Benchmarks* was not a curriculum but a supplement that worked with adopted curricula and adapted to different pedagogical practices.

Designs for Science Literacy (2001) expanded upon *Benchmarks* by focused on the integration of science amongst all subjects, including vocational studies, collects materials for teaching into a whole K-12 model and propositions the ability of teachers, administrators and schools to choose from curriculum materials for a fully aligned progression of learning. As was the case with *Benchmarks*, *Designs* does not try to supplant any local or state curricula efforts, but aims to provide methods for making that curricula more coherent and integrated. The authors of *Designs* states, “curriculum is a mishmash of topics that lacks coherence across subject-matter domains, and grade levels,” thus not contributing to conceptual knowledge creation by students (Designs for Science Literacy, 2001, p. 3).

Strand maps demonstrate a progression of concepts, skills, and content across grade bands. The *Atlas of Science Literacy* (2001) and *Atlas of Science Literacy: Volume 2* (2007) present strand maps across science subjects that exhibit how different topics imbedded within science curricula can be aligned from elementary to high school and cover a multitude of conceptual areas. These differ from concept maps by going beyond one particular moment in knowledge building and expand it across multiple years and domains. *Atlas* was a graphical representation of the information found in *Benchmarks* and *Designs* to better represent the goal of a more connected and concept-based way of building knowledge.

Learning Progressions

Learning progressions offer a structure for aligning and integrating concepts across grade bands through authentic pedagogical practices. Fortus and Krajcik (2012) call for more “curriculum coherence” within and across grade bands. Science classrooms driven by content memorization with a lack of emphasis on higher conceptual integration are antiquated. LPs offer a solution for a more vertically aligned and thematic method of learning. The National Research Council (NRC, 2007) references LPs in *Taking Science to School*.

> Learning progressions in science are empirically grounded and testable hypothesis about how students' understanding of, and ability to use, core scientific concepts and explanations and related scientific practices grow and become more sophisticated over time, with the appropriate instruction. (p.8)

By utilizing more sophisticated methods of learning, LPs answer the call to create a more scientifically literate public.

LPs should explain how to align standards (i.e., NGSS) to teaching (Corcoran, Mosher, & Rogat, 2009). Conceptual understandings can be assessed by teachers overtime with the integration of LPs into the classroom (Mosher, 2011; Wiser, Smith, & Doubler, 2012). LPs include a few major components. (1) LPs must target a final big idea driven by a central theme. (2) LPs need to recognize boundaries of science concepts included and incorporate science practices. (3) Novice, intermediate and advanced operational definitions of conceptual understanding need to accompany a LP. (4) Assessments need to be developed to measure conceptual understanding of students, not basic factual knowledge. The structure, organization, sequencing, and validation of LPs is still under debate (Duschl, Maeng, & Sezen, 2011; Krajcik, 2011).

Pedagogical Content Knowledge

Teachers develop professional knowledge through teaching and experimenting with techniques presented to them during teacher training (Wallace & Loughran, 2012). Pedagogical content knowledge (PCK) refers to teachers' application of knowledge by incorporating content knowledge through proper pedagogical methods. PCK is "the integration or the synthesis of teachers' pedagogical knowledge and their subject matter knowledge" (Cochran, 1997, p.97). A dissemination of knowledge is not teaching. Educating students requires teachers to facilitate learning to connect conceptual foundations of the past to new connections in the present and future.

Most preservice teacher science coursework is offered through an amalgamation of courses that may or may not relate to one another and are often delivered in a direct-teach method (Lyons, et al., 2015). Relying on college coursework for preparing science teachers has been declared a weak model for over 20 years (Lederman, Gess-Newsome, & Latz, 1994). Methods coursework has focused heavily on how to teach, but not always what to teach. Santau, Maerten-Rivera, Bovis, and Orend (2014) found that focusing on content in methods courses can lead to content knowledge gains. PCK of teachers is also a limiting factor with regards to proper LP integration (Krajcik, 2011). Krajcik (2011) states:

> Although some teachers will have the pedagogical content knowledge to develop particular tasks to move students forward, learning progressions need to provide a set of ideas that teachers can modify to fit the needs of their classroom situations. (p.157)

If preservice teachers do not develop their PCK during teacher preparation programs, then new efforts in science education research like LPs will not be effective over time. An emphasis on how LPs and PCK development interact with one another needs to be studied.

Dinosaurs as a Curricular Theme

Informal Science Education

Museums, zoos, aquariums, parks and many other places offer children a wealth of arenas for informal science education. Dinosaurs are often found in science and natural history museums, with their displays including reconstructions, interactive physiological recreations, and information displayed in classic methods to showcase what paleontologists know about these prehistoric beasts. Early on children have access to dinosaurs in educational settings outside of school at both home and informal science settings like museums. Other informal learning dinosaur education include print resources such as books and flashcards. Palmquist and Crowley (2007) suggest that while the amount of dinosaur education resources is vast, these learning supplies may be retelling the same story with basic factual information. This leads to the creation of dinosaur experts in young children with a shallow depth of connections to other science fields. Parents are important facilitators of this early acquired knowledge, especially with novice learners. By having conversations with children about their interests in dinosaurs, particularly in museum settings, scientific knowledge can be broadened. When considering dinosaurs as a topic of science discussion, one must keep in mind that most of what we know about these creatures is based on evidence from the fossil record with established and constantly reviewed scientific arguments. Theories have been revised to reflect new evidence, such as feathers, anatomical posture, and endothermy, thus informal education settings should reflect these findings. When considering extinct species posture, such as neck and head positions in Brachiosaurs, scientists have looked to extant species for support of theories (Taylor, Wedel, & Naish, 2009). Nest sites have been discovered of hadrosaurs in Montana that suggest nurturing behavior and parenting, two ideas that were once not thought to be possible for dinosaurs (Horner & Gorman, 1998). Displays in museums and diagrams in children's science books need to be updated to reflect the ever-changing revelations of the field. Factual importance is an area of concern when it comes to informal dinosaur education, but with proper epistemological scrutiny applied to source materials, then dinosaurs offer an excellent science engagement point for children of all ages.

Media

Another area that has seen a proliferation of dinosaurs has been television and film media. Dinosaurs are present in more than just pre-Kindergarten and elementary school supplies, as they have infiltrated popular television shows over the past few decades. *The Flintstones* was the first primetime animated television series and while the show exposed dinosaurs in a very unscientific manner (e.g., as garden tools, pets, transportation) it still was a prominent spot for an extinct clade of reptiles.

Television shows directed at children have used dinosaurs as an engagement factor in a variety of settings. The 1990s proved to be a time for dinosaurs to sneak into television shows including the *Mighty Morphin Power Rangers* and *Barney and Friends.* While neither show was about dinosaurs as a content subject, the use of appearance of dinosaurs in television shows has been found to increase student interest in the subject (Bauer & Dettor, 1997). The 1990s harkened back to *The Flintstones* with primetime viewing that older children and adults could enjoy in the show *Dinosaurs*, created by Jim

Henson. The show featured an average family sitcom with classic Henson puppets and costumes created to look like dinosaurs replacing normal human actors, but at the same time tackling some scientifically sensitive subjects like climate change (Stoessner, 2012). While dinosaur education was not the primary objective of *Dinosaurs* in the 1990s, the 2000s have seen multiple series about dinosaurs. Early childhood shows such as *Dinosaur Train* air to not only engage students with dinosaurs as a content medium, but to explore the science of dinosaurs and related science concepts (Fitzsimmons, 2013). *Discovery* and *British Broadcasting Corporation* (*BBC*) have both developed an expansive library of dinosaur shows recreated in computer-generated imagery (CGI) that can appeal to older learners and reach science concepts at a much more rigorous depth of field.

Films have used dinosaurs to draw viewers in to theaters starting in the silent film era to present day. Through Claymation, animation, puppeteering and CGI, dinosaurs have made their way onto the big screen for over a century. In many of the films, dinosaurs are either anthropomorphized (i.e., *Land Before Time* [1988], *Dinosaur* [2000]), seen interacting with humans (i.e., *Planet of Dinosaurs* [1977], *Jurassic Park* [1993]), behaving beyond the scope of nature (i.e., *Godzilla* [1954]) or a combination of the aforementioned inaccuracies (i.e., *The Good Dinosaur* [2015]). Clearly the intent is not to make documentaries about dinosaurs, but the accuracy of how they are portrayed seems to be valuable to viewers. *Jurassic Park* (1993) changed the landscape for dinosaurs in film grossing more than $1.029 billion (US) bringing dinosaurs in what appeared to be the most lifelike portrayal yet. *Jurassic Park* and its sequels all opened at more than forty-seven million dollars, with *Jurassic World* (2015) having the largest opening of all-time at the release date of the movie with $208,806,270 and is currently the fourth biggest movie of all-time grossing more than $1.671 billion (Worldwide). Dinosaurs are prevalent in multiple media formats and garner the intrigue of the common public.

Science Publications

Print access to dinosaurs can span many ages of learners, from children's novels to journal publications. Children's books offer some of the same engagement factors found in television and film media with dinosaurs. Dr. Seuss's *Oh Say Can You Say, Di-no-soar? All About Dinosaurs* offers children a nonfiction picture book that teaches the factual pronunciation of many dinosaurs (Worth, 1999). Holtz and Rey's (2007) *Dinosaurs: The most Complete, Up-to-Date Encyclopedia for Dinosaur Lovers of All Ages* was named an Outstanding Science Trade Book for Students K-12 in 2008 and provides a young reader friendly text with annotations by world renowned paleontologists (i.e., Robert Bakker, Jack Horner, Scott Sampson) (National Science Teachers Association, 2008). These two examples are just glimpses into the literature produced about dinosaurs to influence young learners about these prehistoric giants and the science involved with studying these creatures. Michael Crichton's *Jurassic Park* and Robert Bakker's *Raptor Red* offer fictional stories rooted in science that can reach students at the middle and high school grades.

Books create an avenue for written publications that can span from fiction to nonfiction, but journals and magazines distribute current research from leading scientists to the general public. Some of the most popular print magazines that are available to the general public through subscription or at a store include *Science*, *Discover*, *Smithsonian*, *National Geographic*, *Popular Science*, *Scientific American*, and *New Scientist.* From 2000 to 2015, these publications contained 515 articles about dinosaurs as a main subject, with 227 of the articles containing "Dinosaur(s)" in the title. This expansive amount of research not only exemplifies the amount of material available for learning opportunities on dinosaurs, but it also conveys the expanse of research being generated by experts across the world.

Dinosaurs in Education

Research has shown that early childhood interests provide for subsequent development of conceptual understanding and that children express many interests in the realm of science (Johnson, Alexander, Spencer, Leibham, & Neitzal, 2004). This research also suggested that science interests of children show a strong affinity for dinosaurs. Expert children can better use and access knowledge and dinosaurs offer connections to build upon scientific information acquired prior to formal schooling (Gobbo & Chi, 1986). Studies including concept mapping of dinosaur understandings (Chi & Koeske, 1983) and familiarity with dinosaurs (Johnson, Scott, & Mervis, 2004), have shown that elaboration into other science domains are more accessible, as well as the use of prior knowledge to frame new knowledge constructs. In a study using dinosaurs as a content medium, researchers found that when more domain-specific information is learned and prior expertise is accessed, new concepts build faster and connections to other scientific domains are more accurate. (Johnson & Eilers, 1998).

Science Teacher Education, Learning Progressions and Dinosaurs

Rationale

With discoveries in science happening every day, the vast amount of scientific knowledge is infinite. Beginning with the *National Science Education Standards* (NSES) in 1996, researchers and policy makers have made attempts over the years to create a more scientifically literate populous of students by suggesting what content in science is the most important to learn. The sheer volume of topics led to a very content rich and conceptually poor curriculum guide, which has been transformed by the *Next Generation Science Standards* (NGSS) to reflect a more conceptually based curriculum that is integrated within and across grade bands (i.e., K-2, 3-5, 6-8 and high school). With a focus on core ideas, crosscutting concepts and practices within science and engineering, the NGSS has led to an outline that promotes integrated and interdisciplinary teaching through engaging students in skilled learner-centered environments with a focus on specific concepts in appropriate grade levels.

One thing that is evident and suggested by NGSS is the use and support of learning progressions (LPs). LPs offer a clearer way to set standards that align to instruction within and across other grades, thus delivering a beneficial arrangement of content to foster conceptual change in students (Corcoran, Mosher, & Rogat, 2009; Krajcik, 2011). Although the core ideas of the NGSS are presented in a progressive manner, the instructional component of how to engage students in learning the topics is missing. The development of instructional materials to support a more conceptually based and integrated curriculum has been the push of many researchers in the past decade (Corcoran, Mosher, & Rogat, 2009; Plummer & Krajcik, 2010; Duschl, Maeng, & Sezen, 2011; Plummer et al., 2015). One finding in a review of LPs has been the lack of research on how teachers implement the use of LPs in classrooms and planning (Duschl, Maeng, & Sezen, 2011).

Teachers need to have a high level of scientific literacy with the focus on conceptual understanding in the current K-12 setting. Research has suggested that preservice teachers have a low conceptual knowledge in science content (Nilsson & Loughran, 2012; Santau, Maerten-Rivera, Bovis, & Orend, 2014). That should not be a surprise given today's typical college student was born in the late 1990s, the NSES and other non-integrated, fact-laden and content heavy curricula were the guidelines in place the shaped their attained levels of scientific literacy. Preparation of preservice teachers defines the knowledge and pedagogical skills they possess as a classroom teacher (Bybee, 2014). They must also be able to transform that acquired knowledge and abilities into lessons that capture the interests of their students and promote student-centered learning.

Student centered-learning environments (SCLEs) harness the suggestion of NGSS with the promotion of scientific practice through inquiry, hands-on activities and student investigations. SCLEs can be effective in promoting conceptual knowledge gains with proper scaffolding from the teacher (Land & Hannafin, 2000; Land, Hannafin, & Oliver, 2012; Jonassen & Easter, 2012). Concept maps are one way to assess the scientific literacy levels occupied by students before and after a SCLE experience (Novak, 1990; Jonassen & Easter, 2012). Within SCLEs, another critical area of concentration should be student interest. Student interest in science is higher when learning involves hands-on activities (Swarat, Ortony, & Revelle, 2012). However, research has indicated that interest in science declines as students transition through elementary school to middle school (Kerr & Murphy, 2012). Fostered and cultivated science interests in children lead to students with more intrinsic motivation towards science (Alexander, Johnson, Leibham, & Kelly, 2008).

Research has shown that 42% of preschool aged children number one science interest is dinosaurs, yet they are not mentioned anywhere in curricula standards (Johnson, Alexander, Spencer, Leibham, & Neitzel, 2004; NGSS, 2013). It is not uncommon for a specific topic to be absent since science concepts are the focus of curricula; however, attaching a student interest, such as dinosaurs, to a LP allows for students to connect to concepts embedded within and associated with that interest. The goal of this study is to develop a LP that integrates both Earth and life sciences to improve preservice teachers' conceptual knowledge and their ability to transform that knowledge into authentic, student-centered lessons that are aligned with NGSS standards. Ultimately, the study focuses on the use of LPs in science teacher preparation and the impact on preservice teachers' PCK.

Theoretical Framework

Activity theory supports a constructivist learning environment through student-mediate learning (Jonassen & Rohrer-Murphy, 1999). This proposition by Jonassen and Rohrer-Murphy relates to the foundations of activity theory. Engeström (1987) brought activity theory out of the dark and expanded upon Vygotsky's model of mediated artifacts. Activity theory supports tangential relationships between vertices (i.e., Tools and Signs, Rules, Division of Labor) and nested components (i.e., Subject, Object, Community) (Engeström & Miettinen, 1999; Engeström, 2014).

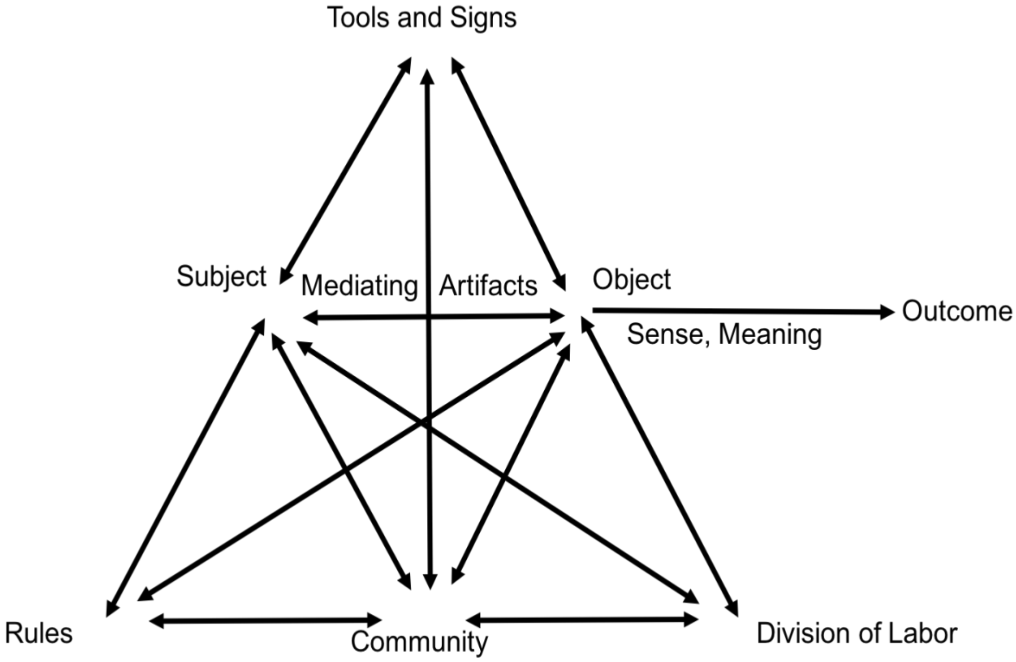

Figure 1. Engeström activity theory model. The model illustrates the relationships between the components of the human activity system developed by Engeström (Adapted from After *Perspectives on Activity Theory* (p. 30) by Y. Engeström & R. Miettinen, 1999, Cambridge, UK: Cambridge University Press. Copyright 1999.).

Jonassen (2000) simplified the cross-system relationships in Engeström's model (see Figure 1) to represent an interacting group of systems (see Figure 2). In activity theory, doing is learning. The subjects of the system are impacted either directly or indirectly by all components of the system and have interrelated subsystems (i.e., Production, Consumption, Exchange, Distribution).

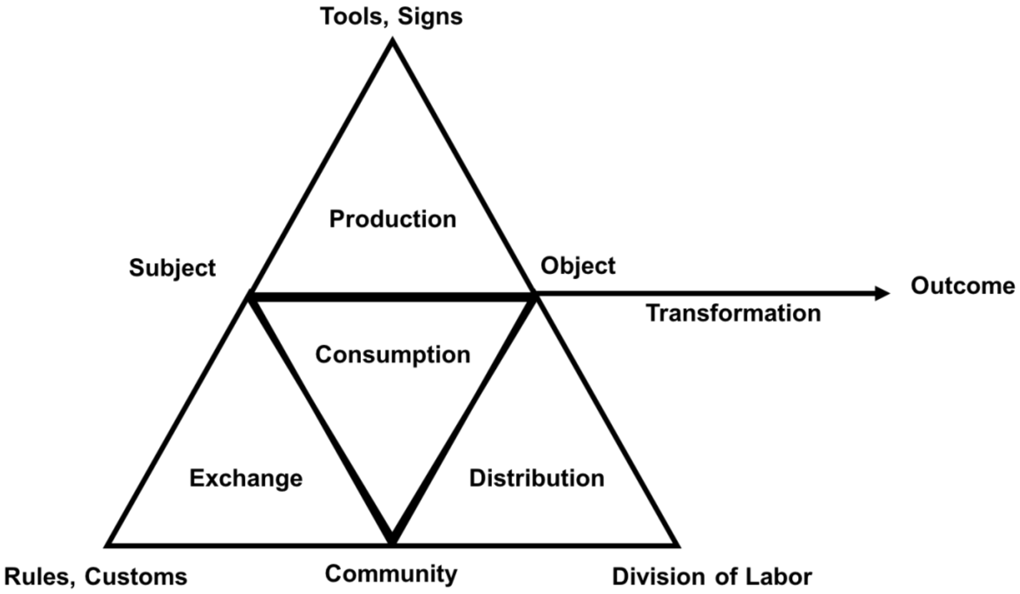

Figure 2. Jonassen activity theory model. The model highlights the subsystems of production, exchange, distribution and consumption. All components are directly or indirectly impacted. (Adapted from After Theoretical Foundations of Learning Environments (p. 99) by D.H. Jonassen, 2000, Mahwah, NJ: Lawrence Erlbaum Associates, Publishers. Copyright 2000.)

Activity theory establishes a foundation for learning environments (Jonassen, 2000) and supports recommendations for more student-centered learning in preservice teacher education (Gess-Newsome, 1999; Gess-Newsome & Lederman, 1993; McNeill & Knight, 2013; Van Driel, Jong, & Verloop, 2002). Jonassen and Land (2000) suggest that activity theory and SCLEs share common goals. Per this suggestion, activity theory supports SCLEs, thus supporting LPs.

Structure of Dissertation

Article 1: Development of an Expert-Derived Dinosaur LP

A LP using dinosaurs as a thematic vehicle needed to be developed to begin this study. No LPs existed on dinosaurs. However, no uniform process for developing LPs exists (Corcoran, Mosher, & Rogat, 2009). In this study, I explored the development of an expert-derived to guide the concepts to base the LP around.

The term "expert-derived" references the use of content (i.e., paleontologists) and pedagogy experts (i.e., science education professors) in coordination with an expert document (i.e., NGSS) to develop the basis of the LP. Concepts derived from this process outlined the scope and sequence of the LP. Based on a panel of experts from science education and paleontology, the LP was developed to use dinosaurs as a theme for integrating science curricula standards across subject barriers. This LP provides a suggested sequence of linked concepts across the domains of Evolution, Ecology, Genetics & Organisms, and Geology. A detailed, qualitative focus on this new expert-derived LP methodology was the initial focus of the study.

Article 2: Impact of a LP on Conceptual Knowledge

The developed LP includes four SCLEs themed around dinosaurs for each grade band (i.e., K-2, 3-5, 6-8, high school). It intertwines topics of Earth and life sciences together with the hope of creating more scientifically literate preservice teachers. By taking part in specifically aligned and coherent SCLEs, I subjugated preservice teachers to the sequence that K-12 students would experience over the course of multiple years during the LP. This intervention aspires to develop a more scientifically literate preservice teacher through the experience of the dinosaur LP. Concept maps, both individually and group, were collected prior to and after the LP as an intervention. Individual and group concepts maps analyzed to measure how overall shifts in the 27 expert identified concepts were impacted by four-week LP intervention. A secondary focus on how distributed cognition plays a role in conceptual development was further analyzed using group concept maps.

Article 3: Impact of a LP on Pedagogical Knowledge

The ability to transform science conceptual knowledge into a student-centered, integrated and authentic science lesson is a key skill needed for a 21st century teacher. LPs incorporate all of the elements needed to meet the demands of 21st century learners. Prior to and after experiencing the LP, preservice teachers developed lesson plans to measure the shift in pedagogical practices as a result of the LP. Lesson plans were scored using a research derived rubric that measures science content integration, authenticity, reformed science pedagogy and student-centeredness.

I set out to measure the use of the LP as an intervention on pedagogical development of preservice teachers and how it relates to lesson plan development, as the final element of this study.

Significance of Study

I had multiple goals for my dissertation. (1) I wanted to develop a new methodology for creating a valid LP using experts. (2) I desired to understand where dinosaurs can be utilized in science education to engage students' interests. (3) I sought to analyze the impact of a LP in preservice teacher education on the development of preservice teachers' scientific literacy and competency to transform conceptual knowledge. (4) I wanted to investigate how a LP can affect science pedagogy of preservice teachers.

I intend to redefine how learning progressions (LPs) can be used in providing an alternative method for teacher preparation. The need for preservice teachers to have higher PCK is a necessity in the 21st century. No longer does a direct-teaching approach reach the needs of 21st century learners, nor is it enough to be the pedagogical method in the modern classroom. Science, especially, needs innovation and inquiry-based SCLEs for students to fully understand the concepts being taught and the nature of how science works. If this study does show higher PCK levels (i.e., better conceptual and thematic understandings and higher quality lesson plans), after engagement in the LP, the results provide evidence supporting a change in preservice teacher education to include more simulated learning in content specific courses. As of now, LPs have only been studied in K-12 settings, as that setting has been the target population for their development (Duschl, Maeng, & Sezen, 2011; Fortus & Krajcik, 2012). This study extends the use of LPs to preservice teacher education.

The development of LPs has been so varied and validity of the LPs has been in question. Establishing a conceptual framework of a new expert-derived methodology for developing a LP with high validity through triangulation contributes to the field of LPs. Chapter 2 of my dissertation recommends an internally valid way of developing a LP and result in a replicable conceptual framework for developing other K-12 LPs on topics other than dinosaurs. Chapter 3 and Chapter 4 of my study provides evidence of how LPs can be used in teacher education and the impact on PCK. By simulating lessons over the course of multiple, adjacent weeks, preservice teachers had a glimpse of how and what students learn in one grade level can impact their knowledge acquisition at a higher grade. The results of my dissertation can offer new methods for LP development and preservice teacher education, particularly in science.

Conclusion

Science education reform has moved to incorporate 21st century skills needed for both students and teachers. With an emphasis on student-centered learning and authentic science, collaborative efforts across science disciplines must happen to create a more integrated and conceptually based method of learning. LPs are an avenue to invoke a more authentic, integrated, and conceptually based way of learning. The promise of LPs is clear for students; however, if reformed based practices remain in research and do not transition into teacher preparation, then these practices remain theoretical structures without impact. The use of LPs with preservice teachers is understudied. Preservice teachers also need to be able to create learning environments that are engaging for 21st century learners, thus a transformation of scientific knowledge into well-developed lessons is a key skill for a 21st century teacher. Developing PCK of preservice teachers must be the objective of teacher education.

CHAPTER II

USING EXPERTS TO VALIDATE SCIENCE DOMAIN CONTENT IN A DINOSAUR LEARNING PROGRESSION

Introduction

Textbook based curriculum efforts of the past offered a nonintegrated and deficient approach to conceptual learning (Fortus & Krajcik, 2011). One might say these old styles of curricula were dinosaurs compared to the innovations of today. Over time, curriculum guides, standards for teaching, and pedagogical practices have evolved. As we look at the landscape and ecosystems of today's classrooms, we find that the most adaptive teaching strategies and structures have prevailed and that slowly, more traditional transmission models of teaching and learning are being replaced by student-centered, active, situated, social learning experiences.

Learning progressions (LPs) were developed as a solution to the curriculum dilemmas of aligning instruction across grade levels and integrating concepts in science towards better conceptual understanding of big ideas (Corcoran et al., 2009). At the conceptual root of LP development was a greater sophistication and mastery of science topics over time (Corcoran et al., 2009; Plummer et. al, 2015). The National Research Council (NRC, 2007) provided an operational definition for LPs in *Taking Science to School.*

> Learning progressions in science are empirically grounded and testable hypotheses about how students' understanding of, and ability to use, core

> scientific concepts and explanations and related scientific practices grow and become more sophisticated over time, with the appropriate instruction. (p.8)

Over the past few years, researchers have been trying to legitimate LPs as reliable curriculum structures that, over time, progress students' development of deep conceptual understanding of thematic topics across science domains.

Corcoran, Mosher, and Rogat (2009) affirm that LPs should provide vertically aligned concept-based instruction, while others (e.g., Mosher, 2011; Wiser, Smith, & Doubler, 2012) contend that LPs should allow for teachers to assess conceptual development over time. According to current recommendations, five elements must be present in well-developed LPs: (1) clear end points around a central theme, (2) well-defined core ideas and practices, (3) operationally defined levels of knowledge and achievement (i.e., adequate intermediate, advanced), (4) learning activities accompanying these operational definitions, (5) assessments developed to measure student understanding. The first two components trace back to strand maps developed for the *Atlas for Science Literacy*, which provided a vertical alignment of topics in the *Benchmarks for Science Literacy* within a defined scientific theme (American Association for the Advancement of Science [AAAS], 1993, 2001, 2007). The other three components are specific to LPs and separate LPs from strand maps. These components go beyond curriculum alignment and mere suggestions of what to learn. LPs propose pathways showing students' learning from a progression of topics in a given time frame, while incorporating assessment in the process (Duschl, Maeng, & Sezen, 2011).

Krajcik and Plummer have developed multiple LPs focused on astronomy-based topics including celestial motion and solar system formation (Plummer & Krajcik, 2010; Plummer et al., 2015). Topics currently formulated by others include microevolution (Metz, 2011), biodiversity (Songer, Kelcey, & Gotwals, 2009), genetics (Duncan, Rogat, & Yarden, 2009), atomic-molecular theory (Smith, Wiser, Anderson, & Krajcik, 2006), and matter (Steven, Delgado, & Kajcik, 2010). No limits exist regarding focus or breadth of topics, time or disciplines infused into LP development. Some LPs have focused on a single grade-level or unit, while others have spanned multiple grade bands throughout the K-12 continuum (Duschl, Maeng, & Sezen, 2011).

Problem Space: Learning Progressions in Teacher Education

Teacher educators must ensure rigorous learning activities that simulate what is expected of preservice teachers once they have classrooms of their own. In *How People Learn*, Bransford, Brown, and Cocking (2000) declared effective teacher education involves "learning activities that are similar to ones that [preservice teachers] will use with their students" (p. 204). These authors also complained that "many learning opportunities for teachers fall short when viewed from the perspectives of being learning, knowledge, assessment, and community centered" (p. 204). Concerns arise, as well, about the proper functioning of LPs in situations involving teachers possessing low levels of pedagogical content knowledge (PCK). Krajcik (2011), for example, offers this caveat:

> Although some teachers will have the pedagogical content knowledge to develop particular tasks to move students forward, learning progressions need to provide a set of ideas that teachers can modify to fit the needs of their classroom situations. (p. 157)

Bransford's team also suggested that successful teacher development includes learning opportunities that "extend over time." Preservice teacher education courses could offer introductory experiences that would allow novice teachers a first opportunity to become familiar with LPs. These introductory LPs could simulate what is expected of preservice teachers once they have classrooms of their own. After a successful introduction to LPs at the preservice level, novice teachers' PCK could grow with more implementations of LPs after they become practicing teachers. These ideas build on studies investigating how teachers' PCK learning progresses (Schneider & Plasman, 2011). However, the effects of teachers' engagement in LPs on their development of PCK has yet to be examined, and "the use of LPs in actual teaching and planning is understudied" (Duschl, Maeng, & Sezen, 2011, p. 169).

The effect of LPs on preservice teachers' development of PCK is an avenue for research that is unexplored, even though some obstacles would have to be overcome. The LP would have to align with coursework of preservice teacher science education courses, while also maintaining the K-12 integrity of the LP. The LP would also have to prepare students for content exams, while at the same time align to simulate grade-level standards. One method for achieving this would be to develop an LP with both K-12 and preservice teachers in mind.

I, as the science preservice teacher educator at a large, southwestern university, found myself immersed within such a practical problem space: planning the development of a LP appropriate for the needs of preservice teachers and K-12 learners. I chose dinosaurs as the topic for developing and implementing an interdisciplinary LP in my university science classes to model reformed science teaching for preservice teachers unfamiliar with more contemporary views of teaching and learning science. My vision was to develop an expert-derived LP for preservice teacher education that would aid in my students' PCK development. The term "expert-derived" denotes that outside individuals with expertise in related fields to the LP are consulted for the developmental process. For this LP on dinosaurs, experts include pedagogy experts (i.e., science education professors) and content experts (i.e., paleontologists). By using experts in both thematic content and pedagogy, I would ensure that the LP would be grounded in conceptual foundations and teaching practices. To actualize this vision, the goal for this study was to produce an internally valid LP through expert derivation consisting of accompanying student-centered learning experiences (SCLEs) for each grade band, as designated by the *Next Generation Science Standards* ([NGSS], NGSS Leads States, 2013). (A secondary goal, unrealized at this point, still remains to use this LP in actual K-12 science classrooms.) Four grade bands exist in the NGSS (i.e., K-2, 3-5, Middle School, High School). My thinking about the development of the LP was centralized around a specialized SCLE for each grade band with a 5E instructional model structure (Bybee et al., 2006).

My intent was to answer the call for teacher educators to engage their preservice teachers as learners in rigorous learning activities that simulate what would be expected of them once they had classrooms of their own. Ideally, my research activities investigating aspects of the implementation of the LP also would provide evidence arguing for or against the use of LPs in advancing preservice teachers' PCK.

Context: Why Dinosaurs?

I love dinosaurs. There, I said it. I love dinosaurs, but so do many school aged children of today and the past. You probably know someone who was enthralled with these magnificent prehistoric beasts as a child or were intrigued about their mystique as he or she grew up. If that does not describe you or a friend, then you at least known someone who contributed to Jurassic World's third largest box office gross of all time ($652,270,625; Box Office Mojo, 2017).

Go to any bookstore or library and you will find a whole section dedicated to dinosaurs. Wander into any preschool, daycare or Kindergarten classroom and you are sure to find a resident dinosaur expert using multisyllabic Latin scientific names that adults have trouble pronouncing. Shows like Dinosaur Train, produced by the Jim Henson Company and PBS, are not only viewable on the televisions of the developing youth, but streamable through every modern platform. Fortified by the expertise of paleontologist Scott Sampson, Dinosaur Train, and other shows like it introduces dinosaurs to the youth of today. Toys, clothing, greeting cards, decorations, stickers, and coloring books are all mediums for these extinct creatures. But why? They were a failure, right?

Not so fast, remember birds are dinosaurs. Dinosaurs have been around since the Triassic and humans have been around for 200,000 years; “that’s a rounding error on the Mesozoic timescale” (Lacovara, 2017, p.9). However, the common person views them as failures due to the term dinosaur quiet literally appearing in dictionaries as a noun meaning outdated or defunct. Dinosaurs are anything but defunct; they are the center of discovery. The unearthing of new species of dinosaurs used to be rare, maybe one a year (Lacovara, 2017). In 2016, 31 new species were discovered. Since the millennium through 2015, 503 articles have dinosaurs as a subject in six of the most popular science publications [*Nature* was excluded as its primary audience is within academia] (Table 1).

Dinosaurs are all around us. They captivate the imaginations of young and old. For many of us, they may have contributed to our first scientific fascination. Higher levels of cognitive development early in life have been witnessed when children are provided the opportunity to have sustained intense interests in topics like dinosaurs (Alexander, Johnson, Leibham, & Kelley, 2008). In a research study involving students entering Kindergarten, dinosaurs have been identified as the number one science interest (Johnson, Alexander, Spencer, Leibham, & Neitzel, 2004). However, you will not find the explicit inclusion of dinosaurs in any of the national science standards (AAAS, 1993; NRC, 1996; NGSS Leads States, 2013). Modern revelations are linking dinosaurs to extant avian species, yet the Class we scientifically catalogued them in is *Reptilia*. A word search in the NGSS for “reptile” will result in no occurrences. Are we not supposed to teach about reptiles? Of course, we teach about reptiles. We teach them within the concepts of evolution, classification, ecology, anatomy, physiology, and other realms of science. The same case can be made for dinosaurs. While it is not uncommon for a specialized topic to go unrecognized in national curriculum guides, I do believe the inclusion of dinosaurs in teaching science had benefits for learners at all grade levels, including university courses.

Table 1

Occurrences of Dinosaurs in Common Scientific Publications

Publication	In title of article	Defined subject term
Science	79	146
New Scientist	73	177
Discover	31	72
Scientific American	17	48
National Geographic	17	35
Smithsonian	7	24
Total Occurrences	224	502

Conceptual Framework

Frank Lester in 2005 expressed concerns about the "what works" movement in the national education research agenda. One of the concerns included current preoccupations with methodological issues of research without considering whether the claims made about the research were based on inferences warranted on the basis of the assembled evidence. Lester offered his perspective that spending time on the conceptualization and design of research studies can alleviate many of this concern. He recommended the use of conceptual frameworks "built from an array of current and possibly far-ranging sources," …, "depending on what the researcher can argue will be relevant and important to address about a research problem" (p. 460). Specifically, Lester recommended that researchers adopt Margaret Eisenhart's (1991) notion of conceptual framework as the beginning point in developing a robust, relevant research plan.

Margaret Eisenhart (1991) took her definition of "framework" from *The Random House Dictionary of the English Language* (1979) as a "skeletal structured designed to support or enclose something" (p. 202). Eisenhart differentiated conceptual frameworks from theoretical and practical frameworks as follows:

> A conceptual framework is a skeletal structure of justification, rather than a structure of explanation based on formal logic (i.e., formal theory) or accumulated experience (i.e., practitioner knowledge). A conceptual framework is an argument including different points of view and culminating in a series of reasons for adopting some points—i.e., some ideas or concepts—and not others.

> The adopted ideas or concepts then serve as guides: to collecting data in a particular study, and/or to ways in which the data from a particular study will be analyzed and explained. Crucially, a conceptual framework is an argument that the concepts chosen for investigation or interpretation, and any anticipated relationships among them, will be appropriate and useful, given the research problem under investigation. … The framework may be based on different theories and various aspects of practitioner knowledge, depending on exactly what the researcher thinks (and can argue) will relevant to and important to address about a research problem, at a given point in time and given the state-of-the-art regarding the research problem. (p. 209)

The bulk of Eisenhart's (1991) paper presented a convincing argument that three conceptual steps are essential in the mental planning process preceding a research investigation. First, a researcher must decide what is to be explained by the study (establish the research problem). Second, the researcher must decide what perspective to use in investigating the problem, considering the options of discipline-based, practice-oriented, philosophical, or pedagogical perspectives. Eisenhart further explained that the researcher's decision of perspective guides the data collection for the study, as well as the concepts and relationships that will be used to "enclose or support" the study. Finally, Eisenhart explained the third conceptual step as one that "begins when data analysis begins" (p. 204). At that point, "the researcher must decide how to reduce the empirical data collected into meaningful categories, how relationships among categories of findings will be specified, and what form the explanation for the empirical data will take" (p. 204).

With Lester's concerns in mind and following Eisenhart's suggestions, I first established the research problem for this investigation; I then built the argument for adopting the perspective for the research; and finally, I formulated a sequence of research questions to guide the collection and analysis of data.

Research Problem

This investigation centered on the development and employment of a general methodology that I, as well as other curriculum developers and education researchers, could use to ground a valid, pedagogically sound, scientifically accurate LP, particularly in the light that no acceptable validation procedures for LPs currently exist. How LPs are structured, defined, sequenced, and validated is still under debate (Duschl, Maeng, & Sezen, 2011; Krajcik, 2011). While various methods have been used for developing hypothetical LPs, one great concern continues to be the internal validity of these LPs for learning (Corcoran, Mosher, & Rogat, 2009). Another concern is that inadequately designed LPs can reinforce immature conceptions and poor pedagogy (Shavelson & Kupius, 2012). In this investigation, I addressed these concerns through the use of expert sources to validate the content of a LP on dinosaurs I desired to develop for a science education course.

Perspective

Considering that the entire concept of LPs stems from recent advances in cognitive and sociocultural psychology (for a review, see Duschl, Maeng, & Sezen, 2011), I adopted sociocognitive perspectives supporting the development of SCLEs. Sociocognitive perspectives are built on “contemporary situated, sociocultural, and constructivist concepts of learning … built on different ontological and epistemological foundations” than those for traditional, more typical, transmission models of instruction (Jonassen & Land, 2000, p. iv). These perspectives shift the emphasis away from traditional models of partitioned teaching of independent units/module of instruction focusing on the mastery of facts and skills. Rather, new models of science and mathematics curricula are vertically aligned, coordinated, and sequential. These curriculum models take into account that students’ understandings about how things in the world work develop over time, concurrently with changes and advances in students’ cognitive and social development that occur with maturation as well as experience. In SCLEs, learning is active, embedded and situated in experience, and socially constructed in everyday experiences reflecting the interdisciplinary nature of the natural world. Sociocognitive perspectives support the positions of contemporary scholars advancing ideas that coordinated and sequenced learning provides for learners’ “growth over time” along conceptual trajectories and learning progressions (Duschl, Maeng, & Sezen, 2011).

Interpretation

This investigation is a part of the larger problem space involving the development of the dinosaur LP for use with preservice teachers. For this investigation, I narrowed the problem space to focus just on the validation of the content for the LP, not on the development of the LP itself. After numerous iterations of the research questions for this study, it became obvious to me that a detailed description of the LP I eventually developed for my course was beyond the scope of this paper. Instead, I settled on four questions to guide the basic research activities and specifically address the validation of expert-derived content included in the LP. I crafted the first three questions to follow Wolcott's (1994) general "formula" of *Describe-Analyze-Interpret* (D-A-I) for conducting and reporting qualitative research. I developed a final, fourth research question to frame my next steps in developing the actual LP to be used with preservice teachers in the university classroom. I chose *Implications* as the label for this final question.

1. What are experts' basic ideas regarding the uses of dinosaurs in teaching science concepts? *(Describe)*
2. What similarities and differences exist among experts' ideas, and what is the consensus regarding a core of basic science concepts? *(Analyze)*
3. How do experts' ideas align the learning goals in the *Next Generation Science Standards? (Interpret)*
4. How does this alignment further inform the development, scope, and integration of concepts for the learning progression? *(Implications)*

Methodology and Procedures

Design

Grounded theory (Corbin & Strauss, 1990) provided the research design for establishing the conceptual framework of the Dinosaur LP, due to the emphasis of this design on generalizability of findings. Grounded theory closely aligned to the object of this investigation establishing the validity of content choices used to structure the LP. In choosing specific qualitative research procedures for the three questions, above all, I considered generalizability above all:

> A grounded theory is generalizable in so far as it specifies given sets of conditions linked through action/interaction with sets of consequences. Naturally, the more systematic and widespread the theoretical sampling, the more conditions and variations that will be discovered, therefore the greater the generalizability, precision, and predictive capacity of the theory. (Corbin & Strauss, 1990, p. 424)

Context

This investigation was framed in reference to the preservice teachers I taught in a uniquely structured course designed specifically for preservice teachers at my university. Described as one of the "content-based courses in science teacher education" offered within the College of Education, the course was designed to emphasize content and pedagogy equally. The course was considered a science course by the university and highlights particular concepts within domains of science (i.e., Earth and life sciences, physical and chemical sciences) during a 15-week semester. Authentic science practices (i.e., using models, carrying out investigations, analyzing and interpreting data, scientific argumentation) and pedagogical methods (i.e., inquiry-based learning, project-based learning) are modeled by the course instructor. Preservice teachers experience class through the lens of the students they will eventually teach in K-12. To qualify as an instructor of the course, individuals must have the equivalent of a masters' degree in the content domains of the course and substantial experience in K-12 science teaching.

Expert Sources

I used two expert groups to establish an expert view prior to structuring the LP. The two expert groups included science education experts and paleontologists, respectively. The science education experts offered insights about the construction of a learning progression through the eyes of an expert in pedagogy; the paleontologists provided expert views about dinosaurs as the content medium or theme for the learning progression. I used the NGSS as an additional expert source to triangular the expert groups' views, after I had analyzed the information from the expert groups. I used the latter source, an expert-developed curriculum guide of standards, to validate essential concepts initially identified by the expert groups for inclusion in the LP.

I selected experts through memberships in international and national organizations in their respective fields. Experts involved in the study all gave authorized permission for the use of their names in any publication resulting from their involvement with the research. Participating science education experts included Molly Weinburgh (Texas Christian University) and Louis Nadelson (Utah State University). Paleontologists participating included Thomas Holtz (University of Maryland) and Scott Sampson (Science World Vancouver CEO, *Dinosaur Train*). I selected the NGSS as an expert document as it was developed by panels of experts from the National Research Council (NRC), National Science Teachers Association (NSTA), the American

Association for the Advancement of Science (AAAS), and Achieve (NGSS Leads States, 2013).

Procedures

I used the four research questions to guide the data collection and the subsequent analysis of that data. The nature of the research questions provided me with ideas about how to reduce the corpus of collected qualitative data into a form that best served the purpose of answering the research questions. I had already decided to collect narrative data in the form of interviews of experts to initially identify the science concepts that would comprise the science knowledge framework for the Dinosaur LP. I used the NGSS to triangulate the information from experts, thus ensuring the content validity of the Dinosaur LP. Creswell and Miller (2000) state:

> As a validity procedure, triangulation is a step taken by researchers employing only the researcher's lens, and it is a systematic process of sorting through the data to find common themes or categories by eliminating overlapping areas. A popular practice is for qualitative inquirers to provide corroborating evidence collected through multiple methods, such as observations, interviews and documents to locate major and minor themes. (p. 127)

My own observations and teaching practices led me to the thematic vehicle of dinosaurs. Interviews were conducted with content and pedagogy experts, while the NGSS was used as an expert document to triangulate the data from the interviews of experts.

Questions existed in my mind, however, about how to best write the answers to the research questions. Clandinin and Connelly (2000) wrote: "Narrative inquiry writers, without over specifying and limiting themselves, need to imagine a shape for the final dissertation text" (p. 153). However, along with imagining the "shape" of the answer, I also needed to choose a narrative form that would best match the research procedures I had chosen to extract the data for the answer. The discussions that follow reflect my decisions about data analysis and reduction, as well as about the shape of the answer, in regard to each of the four research questions.

Designing interviews. Designing the interviews was based upon my first research question. I crafted the first research question because I wanted to know what experts' basic ideas were regarding the uses of dinosaurs in teaching science concepts. I had conducted interviews of experts using a protocol I had developed with a team of science education professors and doctoral students. The interview protocol included five open-ended questions, which I asked in a semi-structured format to allow for follow-up questions on topics introduced during the discussion. I conducted interviews lasting no longer than 45 minutes, using the telephone or digital face-to-face technology. I also transcribed the audio-recordings for future analysis.

I decided to transform the transcribed interviews into a research text that would introduce the participants as credible informants, provide enough information to reveal the nature of the conversations I had with them, a few thoughts about my own reflections on those conversations, and examples of the information they had provided (Clandinin & Connelly, 2000). The research text answering Question One would be an introduction to the informants and the data. I decided to reveal more specific information regarding the actual science content the experts had connected to the Dinosaur LP in the answers to the subsequent research questions.

Utilizing interviews as an expert source. To answer the second research question, I used constant comparison methods (CCM) to analyze the transcribed interviews (Corbin & Strauss, 1990). Answering this question involved identifying the similarities and differences existing among experts' ideas to yield an expert consensus regarding the core of basic science concepts for the Dinosaur LP. Transcribed interview texts provided the input for the analysis process, which consisted of two activities, namely fragmenting and connecting (Dey, 1993). I performed these activities simultaneously as I carefully scanned each of the interview texts to identify significant portions of the text referring to information from the expert reflecting a connection between scientific content and Dinosaur LP development. I used open coding to identify each of these significant portions, which I lifted from the interview as a "content segment." I then assigned one or multiple codes to the content segment, which identified the nature of the expert's connection. I then compared the coded segment with the next content segment in the text. If the second segment reflected the same conceptual connection as that reflected in the first segment, I assigned the same code to the second segment. If, however, the second segment revealed a different conceptual connection, I used a new code to identify the second segment. In similar fashion, I continued the CCM process until I had coded all content segments in all interviews. With the assistance of a science education researcher, I established interrater reliability at 90 percent for coding. The researcher and I then aggregated concept statements into categories reflecting science principles belonging to the domain of either life or Earth science.

The shape of the answer to this research question was somewhat different than that of the first. While I used a narrative style in the answer, I used the research narrative to explain the content of several tables designed to reflect the comparisons I had made within and across the participants' identifications of connections within and across the science domains of life and Earth science.

Aligning coded concepts to NGSS. To ascertain how experts' ideas aligned with the learning goals in the *Next Generation Science Standards,* I used the results of the combined data from Question Two reflecting comparisons between and among experts' responses. In effect, the analysis used to answer Question Three is the last in the sequence of establishing the content validity of the LP. My answer to this question reported the results of comparing the categories of concepts identified by the experts with the categories identified by the experts who developed the NGSS. I then matched the results of the constant comparison of the interviews to learning objectives and coordinating Core Ideas from the NGSS (NGSS Leads States, 2013).

Working with another science education researcher, we examined every grade level of the NGSS to find alignments between the learning objective or Code Idea with the concepts that had been identified by the experts. Only the concepts derived from the narrative inquiry process of interviewing experts were used for inclusion. Our own conceptions of where dinosaurs could fit were not used in construction of aligning coded concepts to NGSS. Ultimately, a list of NGSS learning objectives for K-12 were established as valid for inclusion in the LP (see Appendix A).

Further development of the learning progression. In reference to Question Four, I felt it was important in this investigation to explain how the alignment I generated in Question Three further informed the development, scope, and integration of concepts for the learning progression. In some ways, answering the question in this paper provided a connection between my efforts to substantiate the content validity in Questions One through Three with the first step in the actual development of the LP. The connecting analysis involved the arrangement of Learning Objectives for the LP into the format of an integrated, grade-banded LP. To develop the format, I used a format similar to that of the expert strand maps developed by the AAAS (2001, 2007).

To provide strength to the process of coordinating the NGSS for their final inclusion in the LP, I overlaid individual strand maps reflecting each expert's connections to develop the final strand map. In the final map, I also identified areas of emphasis for the LP; that is, the areas reflecting the most important NGSS-supported learning objectives for the LP. From the final strand map, a team of science education specialists established learning goals for different grade bands.

I, along with a team of science education professors, graduate students and an undergraduate research team, developed sample 5E lessons plans based on the BCSC model (Bybee et al., 2006). The 5E format of instruction was selected as it reflected the perspective chosen by the department for teacher education and its widespread use in classrooms. One lesson per grade band (i.e., K-2, 3-5, Middle School, High School) was developed to be used as an exemplar SCLE. The developed SCLEs were eventually incorporated into a science teacher education content-based course.

The core of the answer to Question Four is apparent in the final strand map (see Appendix B). The NGSS dictated how the map was constructed. Upon construction of the final strand map, the development team collaborated to determine the most appropriate NGSS for inclusion in the four grade-banded exemplar SCLEs. Standards were selected for each grade-band and lessons scaffolded around the 5E lesson format were developed. An attempt to reflect and simulate science teaching and learning, as it should be seen, in preservice teachers' field placements was emphasized during SCLE construction.

Findings

Description of Expert Interviews

Experts involved in the development agreed to identification for added credence to the study. This is a potentially important aspect to this methodology of LP development because these experts provide a validation to the concepts selected for the LP. By choosing a theme and having the concepts develop organically from expert opinions, I was removing my biases as to where I believed the theme fits best. Some themes may be narrower in focus, while other may be broader; regardless, using experts removes a potential dilemma of personal conflict. I know that I would like to use dinosaurs to teach evolution, but if that topic does not present itself within the interviews, then it would not be an area of emphasis for the LP. Also, having an expert derivation takes into account content and pedagogy equally. The same number of experts were used for each, thus neither expert opinion was valued more.

Science education experts. The science education experts for the development of the LP had taught preservice teachers, K-12 teaching experience and research agendas in science education. The eventual goal of the LP specified design was for use in a preservice science education coursework, as well as K-12 classrooms. Having experts that have taught at both levels was important.

My first interview. My first interview was with Molly Weinburgh. I first met Weinburgh at a national research conference for science education. Weinburgh is the current William L. & Betty F. Adams Chair of Education and Director of the Andrews Institute at Texas Christian University (TCU) (TCU, 2017). A 2011 Fellow in the American Association for the Advancement of Science (AAAS) and past president of the Association for Science Teacher Education (ASTE), Weinburgh brings an expertise for inquiry-based science instruction and teacher education to the study. Also, she taught biology for 16 years prior to her career in higher education. After getting to know her research, outreach, and teaching accolades, she became the first expert for the LP. Her involvement would set the foundation for the LP. Although she was the first interview, her expert opinions did not impact how future interviews were conducted.

I went over my interview questions one last time before I sat down for the first video interfaced interview. I would inform Weinburgh how the project and inspiration for pursuing LP research began. I provided findings about the lack of dinosaurs in science curricular standards, both nationally and a state-levels. Then began the first time

I would attempt to explain my fascination with dinosaurs to one of the experts in the development process.

Weinburgh and I would go onto discuss if she had used dinosaurs in her classroom before. Upon talking about her 20 years of K-12 teaching being at the high school level, Weinburgh shared the following.

> Utilizing dinosaurs to show the variety that we can have when we lump something altogether. You know so we lump together dinosaurs, we lump together flying ones, walking ones, ones that probably were more water bound, not totally water bound but more water bound, so really talking about diversity and that has been very successful with, again, fourth, fifth, sixth grade students.

A great answer and such a relief that she had used dinosaurs in her teaching. In her response, she was talking about flying and swimming dinosaurs. A dinosaur enthusiast or expert like a paleontologist would be ready to make the distinction that swimming and flying prehistoric reptiles were not actually dinosaurs. This statement not only provided evidence that we can use dinosaurs in science teaching, but experts in content are needed for the development of a quality LP.

After the initial question, the discussion became about where dinosaurs could be utilized. Weinburgh would elaborate,

> Certainly, as we look at young children we know that young children from about the age of three sometimes, to about the age of nine, a huge proportion of them are just fascinated with dinosaurs. Any time we can bring in a topic that already is of great interest, all of our reform documents and not just ours but if you look

> at teacher education in general, over and over again it's be relevant, bring in things kids are really interested in, find out their interest areas.

This statement gave credibility for the reasoning behind an LP on dinosaurs. Others have been developed in space (Plummer & Krajcik, 2010; Plummer et al., 2015), genetics (Duncan, Rogat, & Yarden, 2009), and biodiversity (Songer, Kelcey, & Gotwals, 2009), all topics of interest for different age groups of students. Specific topics came up in conversation. "The whole process of fossilization, that might certainly be a place to bring in more about dinosaurs than just that we have fossils of them," said Weinburgh. While an obvious tie-in to the curriculum, her follow up would expand into a multitude of concepts.

We discussed the different grade levels. "Lower grades in subjects other than science, talk about geological time, so to think about multiple ice ages, multiple changes in the earth as we know it and that the dinosaur is an example." This would provide the underlying theme for our dialogue. We would go on to discuss more about advancements in our knowledge about dinosaurs. Earth and life science concepts emerged at the prevalent locations for dinosaur thematic learning.

The final point of emphasis shared was the ability to integrate authentic practices and the nature of science into a dinosaur LP. "If people understood about how science works, they'd understand how the definition of planet could change as we know more and therefore something that used to fit the definition doesn't fit it anymore." This would prove to be a necessary component of the eventual dinosaur LP.

A second science educator. Louis Nadelson is the current Director of Sponsored Programs and Academic Research at Colorado Mesa University (Nunn, 2017). Prior to his new position, he faculty appointments have focused in STEM learning theory, teacher development and inquiry curriculum design at Boise State University and Utah State University. With nearly $10 million in grants, Nadelson offers an expert perspective on curriculum design ingrained with authentic science pedagogical practices.

I would meet Louis Nadelson for the first time at the American Education Research Association (AERA) meeting in 2016. We began to discuss his work with concept inventories and evolution based education. At this time, the topic of dinosaurs came up and I would ask if he would like to potentially be an expert for a LP I was designing on dinosaurs. We would go on to correspond via email, with an official recruitment to this project being initiated.

Nadelson and I began the interview by discussing some of his past research. When referencing participants knowledge of dinosaurs from his research, he shared, "I think that they understand that dinosaurs and humans didn't happen at the same time, but they still don't accept human evolution." This could be understandable for a younger student population that does not fully grasp the concept of evolution. Unfortunately, the population of that study included university students.

Nadelson would be the perfect follow up to Weinburgh. We continued to discuss the goals for the research and development of a dinosaur LP. He instantly picked up on the idea of a learning progression and proposed some wonderful insight.

> What the students are ready for, in terms learning progressions, I usually think of those as conceptual development of understanding a concept, where there's the other part about that is the curricular development of what builds on in terms of how does the curriculum progress as well. One of them is, how much does an eight-year-old understand extinction compared to 16-year old? And, where would be the conceptual gaps in that learning progression there, in terms of understanding. You've got a pretty interesting situation because we essentially don't teach that in the curriculum.

This statement would provide a credibility and support for the development of an LP focused on dinosaurs. Now, two experts in science education have expressed the value of the LP.

He would go on to share stories about finding fossils in the desert, something that I have never done. Although I am fascinated with dinosaurs, the only fossils I had ever seen were in a display at a museum. We continued to discuss about how he brought fossils into his Earth science classroom and the excitement it brought his students. Once again Earth science was a key area of emphasis.

We moved on to the key interview question about where dinosaurs could be employed in the current standards. Nadelson and I would discuss teaching evolution. He stated, "I think just to understand deep time, that these critters lived a long time ago, and they lived for a long time when they were around, too. So, to try to understand deep time and in terms of evolution, I think that might be helpful." This was a wonderful statement and provided the chance to integrate Earth and life science concepts.

As I was contemplating his response, one of the best suggestions would be presented in terms of linking elementary and upper level science. In reference to some of Nadelson's research we discussed this vertical alignment.

> I think that also, as you saw in the kindergarten to second grade evolution paper, the importance to see the morphology or the similarities in structures. If you start looking at the bone structure of a dinosaur and a bone structure of a modern-day lizard or a human or a dog, you're going to see a lot of overlap in the kinds of bones structures you see. Maybe there's something going on here, and using the dinosaurs for doing that, and try and draw a parallel.

The conversation continued to integrate various Earth and life science concepts. Nadelson would continue to suggest relationships of science being learned at different grade-bands and how dinosaurs could be used to close the gap.

In addition to the emphases in Earth and life science, Nadelson would also provide a suggestion for the disappearance of dinosaurs from the K-12 setting. We discussed how in the past dinosaurs were taught in multiple elementary grade levels. This dedication to a topic would be great for the LP. However, when discussing the depth of what was being taught, Nadelson's observation was nothing more than basic facts about dinosaurs. The efforts of this LP development would be applauded by Nadelson because he liked the notion of using dinosaurs as a thematic component. Using dinosaurs as a theme made the learning about the science concepts he would reference throughout the interview in Earth and life sciences.

Once again, the nature of science would be a large point of emphasis for the conversation. Nadelson would go on to suggest questions that we could pose to students that would address nature of science components and their comprehension of various science concepts. Questions included:

> How do you put those back together fossils to form a dinosaur, and then what can you tell by that? How do they know whether they were plant eater, meat eater, omnivores? How can they tell about reproduction? How can they tell about what they might have looked like on the outside versus the inside? What do we know about their organ structures inside, do we have record, and why don't have record of that, if we don't? What happens to soft tissues in terms of fossilization? What does that lead us to do, in terms of putting together the big picture of what's going on with the digestive system of a dinosaur?

Nadelson's contributions would end up being highly integrated to development of the LP. Suggestions would guide the structure of the SCLEs and the emphasis on deep time would be later referenced by the paleontologists.

Dinosaur experts. The search for paleontologists to participate in the research and development might have been as difficult as finding an actual dinosaur fossil. Due to limited resources, phone calls, and email messages were the method for trying to entice participation. I reached out to over 20 paleontologists and got two to participate. The difficulty of finding contributing dinosaur experts led to the limited number of experts for LP development.

Tyrannosaur expert uncovered. Thomas Holtz is a vertebrate paleontologist and Principal Lecturer in the Department of Geology at the University of Maryland. Author of *Dinosaurs: The Most Complete, Up-to-Date Encyclopedia for Dinosaur Lovers of All Ages* (2007), Holtz's expertise is not confined to his lecture hall. He is passionate about outreach and can be seen on multiple dinosaur documentaries. Two courses that Holtz teaches include Geology 104, *Dinosaurs: A Natural History* and Geology 204, *Dinosaurs, Early Humans, Ancestors & Evolution: The Fossil Record of Vanished Worlds of the Prehistoric Past*. Along with multiple other courses and being one of the world's most expert authorities on *Tyrannosauridae* phylogeny and functional morphology, Holtz brings an expertise on dinosaurs in the classroom rivaled by few.

Thomas Holtz was the first paleontologist I interviewed. I reached out to him due to his efforts in outreach via his encyclopedia on dinosaurs and appearances on dinosaur documentaries. I was in Washington, D.C. for AERA and a short commute away from his location at the University of Maryland. Holtz was the most eager and detailed interview that I would conduct. I emailed him, hoping to meet with him on campus, but due to scheduling we decided to conduct the interview through a video interface.

The day of the interview I was excited to talk with a paleontologist that I had watched on documentaries in the past. I stayed up the night before the interview watching dinosaur documentaries. I toured the Smithsonian National Museum of Natural History the morning of the interview. Holtz and I would begin the conversation about dinosaurs and the curriculum (Holtz, 2016). He was shocked to learn of the lack of specificity in standards and the absence of dinosaurs in examples. “Oh my God, wow,” was his exact response. After sharing documents about science standards, Holtz and I began to talk about dinosaurs in the classroom.

Unlike the science education experts, Holtz taught about dinosaurs at the collegiate level. We would then talk about how and why his courses were developed.

> The class that brought me to the university was I created a course, *Dinosaurs in Natural History*, Geology 104, which I've taught since 1994 here. It's the class I've taught most often. That one is, you know, when I explain the origin of it to people, I say I was brought on here to pimp dinosaurs. The idea was that at the time, the department was going, so the university was going through one of its budget cut cycles. The word was in the pipeline that if departments didn't have enough seats in classes, they might be threatened with being cut. They wanted some classes that had high attendance, and so at about the same time, my resume came by. It was a dinosaur class. It was intended for non-majors, and it uses dinosaurs as the way of introducing how paleontologists and biologists and geologists approach questions.

The idea of creating a class for college students because of a high interest in dinosaurs for non-geology majors perfectly aligned with my aspirations to use this LP in teacher education. If Holtz had one of the most popular classes at a university, then it was worth an attempt to continue the pursuit of this LP for use with preservice teachers. Given the known high interest level of K-12 students, especially elementary-aged children, there was a chance this would work with education majors concentrating on pre-Kindergarten to middle school certifications.

Holtz followed his statement with, “had the course been called, multituberculates, a natural history, or cycads, a natural history, no one would take it.” Dinosaurs were the hook to learning the content. Trying to further understand what could be taught with a thematic foundation of dinosaurs was the next topic. Holtz shared,

> Dinosaurs, everyone loves. Through that, I talk about the geological side, paleo environments, sedimentology, geologic time, and geologic change. On the biological side, I can talk about ecology, evolution, systematics, extinction, functional anatomy, and physiology, behavior, growth, ontogeny, and all these different inter-related topics using dinosaurs as the focal point. That way, you know, even though I don't expect most of the students go on to work on dinosaurs, a handful have, but most of them aren't going to, but they'll have been introduced to these different types of approaches to understanding the world around us using dinosaurs as the examples.

Knowing what concepts Holtz emphasized was a valuable insight for subsequent analysis of the interviews. Although his course was titled, Geology 104, he combined both Earth and life science realms in the same class. Once again, Earth and life sciences were emphasized as the main domains of science for this LP.

We would progress to more in-depth topics about specific dinosaurs, geologic time periods and how ecology could be taught using dinosaurs. Holtz would go on to comment, “you could probably find a place to use dinosaurs as examples of something in science at almost every step along the way in K-12.” Holtz was still stumped by the lack of detail in some standards and the dinosaur void.

The nature of science and skills for learning science were once again an emphasis. Holtz referenced *Dinosaur Train,* “The odd thing is at the same time that they're not talking about it there, you get *Dinosaur Train* on PBS, which is teaching little kids what's a hypothesis? A hypothesis is a type of question you can test. They know to use it.” He emphasized dinosaurs as “the anchors to pull people in,” and could not figure out how a television show figured that out but not curriculum designers. This show is geared for preschool to early elementary students, yet highly sophisticated scientific language is being used properly by children that are just beginning their educational journeys.

Holtz and I would go on to discuss specific instances including using different teeth in models for sorting based on dietary needs, footprints to determine behavior (e.g., pack hunters, herding, solitary species), and using a roll of paper with significant evolutionary emergences at different measurements to represent deep time. All of these examples were adopted for the SCLEs of the LP. Holtz’s interview would be the most robust, detailed and impactful of the four interviews. I had shared with him my struggles to get dinosaur experts involved. At the conclusion of our talk, he provided some suggestions for paleontologists to recruit. One of his suggested dinosaur experts was Scott Sampson.

Dinosaur Train, all aboard. I would reach out to all the suggested paleontologists and continue to pursue some of the ones that had not respond to previous recruitment efforts. I would contact Scott Sampson through his website, as the contact information I first used was out-of-date. I received a response that Dr. Scott was on board. Sampson and I would schedule the interview for the first week in 2017, 15 months after my first interview with Weinburgh.

Scott Sampson the current CEO of Science World British Columbia, a former curator of the Utah Museum of Natural History, and host of the PBS Kids television show Dinosaur Train. He is one of the most recognizable dinosaur paleontologists in the world with outreach including hosting and advising the Discovery Channel series *Dinosaur Planet*, television appearances on popular talk shows (e.g., *The Today Show, Good Morning America*), and being featured as an expert in numerous dinosaur documentaries. His book, *Dinosaur Odyssey: Fossil Threads in the Web of Life* (2009) provides insights into his and others' discoveries over the past few decades. While he may be known as Dr. Scott to the fans of *Dinosaur Train*, Sampson is a renowned expert in dinosaurs with a passion for education outreach.

Due to his wide-ranging commitments, my interview with Sampson would be the shortest of the four talks. However, the perspective of early education was needed. His work with children and dinosaurs was unique. For anyone unfamiliar with Scott Sampson, he is the Carl Sagan or Bill Nye of dinosaurs. To a whole generation of young learners, he is *the* dinosaur expert. Just like Sagan and Nye, Sampson is responsible for science education outreach through television. However, he not just a television personality, but a former professor and current director of Science World in Vancouver.

Sampson's enthusiasm for aiding in the development of the LP matched my excitement of being able to speak with him. Just as Holtz, Sampson also taught courses at the university-level about dinosaurs. Sampson (2017) stated, "I was a university professor for a number of years and I taught an intro level dinosaurs course that attracted a couple hundred students, at least. I think it is now up to 350 or 400 students." Once again, there was an interest in dinosaurs all the way from pre-Kindergarten through college. He discussed the topics for the class, "It uses dinosaurs basically as a vehicle to talk about a full range of scientific topics. Everything from genetics, to plate tectonics, to climate change, to evolution, to adaptation, to ecology, to geology."

During the interview, Sampson said he was staring at a pigeon outside of his window and it was a "direct descendant of little feathered raptor dinosaurs." "Dead as a dinosaur," was the phrase that proved to Sampson that dinosaurs need to be integrated into evolution units. We began to discuss the evolutionary relationships between dinosaurs and birds. This made me think back to when I was teaching high school biology and would use dinosaur evolution as a way to circumvent any misconceptions about evolution. When discussing this topic further he shared,

> We're still living in the age of dinosaurs more than the age of mammals. Just saying things like that gets people to really think. It opens their eyes about the present day and how the present day relates to the past.

Dinosaurs as a “primary vehicle” was his way of affirming a thematic LP on dinosaurs was a worthy endeavor to pursue.

Our discussion progressed to the topics for dinosaurs in science. Sampson offered, “You could use dinosaurs to at least introduce and really teach almost any major area of biology and the majority of areas in Earth sciences.” The learning progression had to be grounded in Earth and life science domains. While physics was referenced by Sampson and Weinburgh, it was more of a passing example and not a thematic connection. Other topics like climate change, geologic time, and ecology were discussed.

Sampson’s reaction to dinosaurs not being integrated into the curriculum was that “it’s a missed opportunity.” He would go on to say that it is “no surprise” because “most people do not think synthetically about topics.” We discussed how we use a “siloism” approach to teaching and do not integrate our domains of science well in the classroom.

I shared with Sampson the vision for using this LP as a way to challenge preservice teachers to think about the big picture of science and not just the specific unit they are teaching. Sampson identified how dinosaurs could be valuable for teacher training:

> One of the things that you might be able to provide is the tools that would connect them, so these in-service teachers and these teacher training programs, they could see that, hey, kids love dinosaurs and here's this easy way to integrate them into my science class that relates to Earth, life, climate, and all of these different topics that I need to teach anyway, and I want the kids to be engaged.

> So, they just need the tools to be able to do it. I think that if people had those tools and they were aware of them and they were demonstrated…you would find more teachers using them and therefore, you'd find them in the curriculum more.

Sampson along with Weinburgh, Nadelson, and Holtz offered insights about where and how dinosaurs could be used in the science classroom. Earth and life science domains would be the major areas of emphasis. This alternative method of developing the parameters for a LP provides acumens cannot be accessed anywhere else. Interviews with students in K-12, a team of education researchers or some combination of the two does not provide the amount of conceptual, subject-specific, and pedagogy recommendations for a particular thematic concentration.

Expert developed standards. The NGSS were developed by National Science Teachers Association (NSTA), the National Research Council (NRC), Achieve with 26 partnering states and the American Association for the Advancement of Science (AAAS) (NGSS Leads States, 2013). This document was used as an expert for the development of the LP. As an expert, the NGSS provided a guideline for the building the scope and sequence of the LP. Core Ideas for coordinating grade levels specified the limitations of how rigorous a specific concept was to be taught. The crosscutting concepts that would later be integrated into the SCLEs of the LP were designated based upon grade-level and this helped the development team integrate these skills. While the NGSS were not able to be interviewed like the other experts, I meticulously became familiar with how the concepts were structured in different grade bands. Elementary standards were much more specific because they were delineated by specific grades and not just the grade bands. Middle and high school organization left for a much more open interpretation for the development of the SCLEs.

I chose to use the NGSS as a third expert, rather than have paleontologists that were unfamiliar with science standards go through a list and just pick out which standards could be used. At the same time, I did not want science education experts, potentially unfamiliar with dinosaurs, choosing the standards. Rather, their interviews were transcribed and coded. At this point, myself and a team of colleagues would analyze all the codes pairing them with the NGSS learning objectives and Core Ideas.

Analysis of Expert-Derived Concepts

The next step after identifying and talking with experts was to analyze the transcripts of the interviews. I transcribed the expert interviews. A science education professor and myself would code the interviews. Constant comparison coding was completed on the four transcripts and resulted in 27 main concepts emerging from the discussions. Table 2 provides a concise look at the 27 concepts that span life and Earth science domains of knowledge. Checkmarks are used to show the emphases of different experts. While not every concept in Table 2 was mentioned by all experts, an agreement among the research team was to include any concepts mentioned by multiple experts that included some tangential relation to another concept. It is also worth noting, during the coding process Inquiry and Scientific Argumentation were codes identified by the researchers. However, in the next phase of comparison to the NGSS, Inquiry and Scientific Argumentation are embedded in the nature of science within the standards' learning objectives, performance expectations and Core Ideas.

Table 2

Emergent Concepts After Expert Interviews

Concept	Weinburgh	Nadelson	Holtz	Sampson
Adaptations	X	X	X	X
Behaviors	X		X	X
Competition	X	X	X	
Diversity	X		X	
Ecology	X	X	X	X
Environmental Change		X	X	X
Evidence	X	X	X	X
Evolution	X	X	X	X
Extinction	X	X	X	X
Fossils	X	X	X	X
Genetics & Organisms	X	X	X	X
Geologic Time	X	X	X	X
Geology	X	X	X	X
Growth	X		X	
Habitat		X	X	
Inheritance		X	X	
Life Cycles			X	X
Mutations	X			X
Natural Selection		X	X	X
Plate Tectonics		X		X

Table 2 Continued

Concept	Weinburgh	Nadelson	Holtz	Sampson
Predator-Prey Relationships	X	X	X	
Reproduction		X		X
Resources			X	X
Rock Layers/Strata		X	X	X
Structure & Function (Morphologies)	X	X	X	
Survival	X		X	X
Traits	X	X	X	X

These concepts present inherent hierarchical relationships that build towards a bigger idea of understanding dinosaurs in the context of integrated Earth and life sciences. A necessary element of any LP, is the big idea. By choosing a theme that spans life and Earth science, I knew there was a possibility of the LP covering a multitude of topics. However, rather than just sitting down with a team of invested researchers to develop what we thought should be included, I relied on the experts. Instead of imparting my own biases into the research and design of the learning progression, I defaulted to experts.

Interpretation of NGSS

The 27 expert-derived concepts were compared to the NGSS. A collaborative effort between a team of science education researchers, NGSS learning objectives and Core Ideas were identified. The selected NGSS would become integral parts of the LP framework. With all the concepts residing in life or Earth science, physical, and chemical science Core Ideas were eliminated from consideration. It was key to keep the big idea of the LP in mind while making this decision. Had the interviews highlighted topics like energy production with fossil fuels, then other concentrations outside of life and Earth science would have warranted consideration.

After narrowing the focus NGSS learning objectives were selected. The NGSS that are including in the dinosaur LP can be found in the Appendix A of this study. Early elementary, K-2, concepts resulted in 3 standards identified for Kindergarten, first and second grade. Late elementary found no relevant standards in fifth grade and only two coordinating standards for fourth grade. Third grade accounted for eight different NGSS over four domains of life science. Due to the NGSS not separating middle or high school by grade-level, identified NGSS were only be denoted by the grade band as a whole. Middle school included seven life science NGSS. Four NGSS represented the Earth Sciences in middle grades. High school NGSS were heavy with 11 life science standards and a mere two Earth science standards were selected by the research team for inclusion.

After selection of NGSS was complete, domains were identified to align with the 27 main concepts and previously hypothesized domains (i.e., Ecology, Evolution, Genetics, Geology, Organisms). The 27 expert-derived concepts coordinated with the four NGSS domains of and were determined to be Ecology, Evolution, Genetics & Organisms, and Geology. Categorizing standards into the developed domains is the final step before strand map construction. Table 3 provides a look into standards selected by grade band and organized by the four final domains.

When visualizing what domains were covered at different grade-bands, developers of an LP can see where learning must begin to meet final progression goals. For this progression, Genetics & Organisms topics should dominate a first-grade lesson incorporating dinosaurs. Late elementary, primarily third-grade, continued the focus on Genetics & Organisms, while progressing the knowledge to now incorporate Evolution concepts. Some Ecology begins to be referenced in later elementary and a small lesson could be developed for fourth-grade to include Geology concepts integrated with Genetics & Organisms concepts for coordinating standards. Middle and High School become trickier due to NGSS not grouping by grade level, thus the development team should reference the target audience for development. Continuing the trend of the late elementary grade band, Middle School offers opportunities to incorporate dinosaurs in any of the four domains simultaneously. The High School grade band has a greater focus in life sciences, which would synchronize well with biology courses. NGSS in the domains of Evolution and Ecology would be the primary emphases for conceptual learning of the LP at High School. The domain of Genetics & Organisms includes concepts that would integrate seamlessly into Evolution and Ecology domains. Geology related concepts peak in Middle School, but could still be used as supporting standards in High School.

Table 3

Identified NGSS by Domain and Grade-band After Coding and Selection

Concept	K-2	3-5	Middle School	High School
Ecology				HS-LS2-1
				HS-LS2-4
			MS-LS2-1	HS-LS2-6
		3-LS2-1	MS-LS2-4	HS-LS2-8
Evolution				HS-LS4-1
		3-LS4-1		HS-LS4-2
		3-LS4-2	MS-LS4-1	HS-LS4-3
		3-LS4-3	MS-LS4-2	HS-LS4-4
	2-LS4-1	3-LS4-4	MS-LS4-4	HS-LS4-5
Genetics & Organisms	K-LS1-1	3-LS1-1		
	1-LS1-1	4-LS1-1		HS-LS3-1
	1-LS1-2	3-LS3-1	MS-LS1-5	HS-LS3-2
	1-LS3-1	3-LS3-2	MS-LS3-1	HS-LS3-3
Geology	2-ESS1-1			
	K-ESS2-2		MS-ESS1-4	
	2-ESS2-1		MS-ESS2-2	HS-ESS1-5
	K-ESS3-1	4-ESS1-1	MS-ESS2-3	HS-ESS2-7

Table 3. Organizes identified NGSS from coded expert interviews by grade-band and final domains.

Implications of Strand Maps and Student-Centered Learning Environments

Strand Map Development. Prior to LPs, strand maps were a method for taking curricular standards, Benchmarks, and organizing them into a vertically aligned framework (AAAS, 1993; AAAS, 2001; AAAS, 2007). Following the domain development for organizational purposes, a hierarchical, vertically aligned strand map was developed to create a representative visualization of the LP (Figure 1). With the focus of this study aiming to build a new methodology for constructing expert-derived LPs, the subject matter of LP will only be represented by the constructed strand map for the LP. A detailed explanation of NGSS is beyond the scope of this methodological article. The strand map allows the LP developer to start to visualize how different standards interrelate to one another. This helps with the development of scientifically authentic and aligned SCLEs.

The identified domains (i.e., Ecology, Evolution, Genetics & Organisms, Geology) go across the x-axis and grade-bands (i.e., K-2, 3-5, MS, HS) align on the y-axis. Coordinating standards are placed in the main coordinating domain and grade-band. Some NGSS may fit multiple domains, but for strand map construction a primary domain must be identified by the research team. Once standards were appropriately placed, connections (e.g., arrows) were drawn between standards to signify relationships of vertical alignment.

Student-Centered Learning Environment Development. Upon conclusion of the strand map construction, organization of NGSS is illustrated with links between standards. These links in the strand map provide a sequencing for how to deliver instruction so that the big idea of the LP can be realized. A strand map allows the developer to predetermine how different identified standards can be taught simultaneously in an integrated fashion through authentic student-centered lessons.

Following the ideology of Land and Hannafin (2000), the SCLEs for LP should promote hands-on, experiential, and facilitated learning environments. The developer of the LP needs to go beyond self during SCLE development. A team is suggested for SCLE design. This is the time when the theme came back into the design. Prior to this it was all about identified Core Ideas and expert-derived concepts. This is the developmental phase that moves the strand map into an LP. The theme should progress throughout the learning as the students gains more knowledge towards the overall big idea of the LP.

No LP would be whole without assessments. This includes the proposal of operational definitions for different levels of knowledge acquisition (e.g., Novice, Intermediate, Emerging Expert, Expert). Each SCLE that is developed needs to include formative and summative assessments that allow the teacher to assess student progress.

Pedagogical methods for the SCLEs were scaffolded around the 5E instructional model (Bybee et al., 2006). This helped to ensure the foundations for SCLEs set forth by Land and Hannafin (2000). SCLEs created for the dinosaur LP included inquiry activities in whole-class, small-group, individual, and station-based methods. Beyond the organization of learning, inquiries included game-based learning (e.g., *Evolution* the board game with special dinosaur trait cards), integration of quality media (e.g., PBS, BBC, Discovery), infusion of experts (i.e., Holtz and Sampson outreach materials), predeveloped materials (e.g., dinosaur curricular support materials from American Museum of Natural History), hands-on labs (e.g., dinosaur dig), and accurate representations of science.

This particular LP was developed with the intent of using it as an intervention in science teacher education coursework. The pre-developed materials would allow preservice teachers to work with quality support for lessons that already exists. Working with hands-on labs, would allow for them to experience inquiry-based pedagogy in a science classroom. Infusing the experts and quality media demonstrated the necessity of supporting 5E lessons and SCLEs with authentic science content. A more detailed recounting of the SCLEs for the dinosaur LP are beyond the scope of this methodology article for expert-derived LP design.

Expert-Derived Learning Progression Methodology

It is imperative that I provide a concise form of methods for developing LPs using experts. The previous text in methods and findings support this developed methodology as an alternative method for developing LPs. This is not a claim that using experts is the only way to develop LPs. Instead, this methodology provides a method to increase the internal validity of a hypothetical model prior to enactment in the classroom.

Expert-derived LPs can be completed in ten consecutive steps. (1) Begin with identifying a topic of high-interest as a thematic vehicle for learning. (2) Identify content and pedagogy experts to support chosen topic. (3) Conduct interviews with experts about the inclusion of the thematic vehicle in current science classrooms. (4)

Code transcribed interviews to distinguish concepts and preliminary overarching domains (i.e., Ecology Evolution, Genetics, Geology, Organisms) of the LP. (5) Utilize current curriculum standards (i.e., NGSS) to identify standards associated with expert-derived concepts and domains. (6) Select domains (i.e., Ecology, Evolution, Genetics & Organisms, Geology) to encompass concepts and align with standards. (7) Visualize the vertical alignment and cross domain integration through the construction of a strand map. (8) Describe knowledge levels, as well as overall knowledge claim of the LP. (9) Create SCLEs with internal developmental team to reflect authentic science practices and proper pedagogy for 21st century science learners. (10) Build or locate supplementary learning materials needed for SCLEs.

Discussion

While there is no clear developmental method for LPs (Duschl, Maeng, & Sezen, 2011; validity addressed by Corcoran, Mosher, and Rogat (2009), this methodology for developing a LP requires a reliance on experts and not self. By having experts in both pedagogy and content involved in process, LPs have the chance of being both more authentic and internally valid. Expert ideas provided the basis for organizing the SCLEs, building the lessons and setting the novice, intermediate, and advanced levels of knowledge for the LP on dinosaurs. Also, the LP became more teacher friendly by coordinating with the NGSS.

The need for experts to be involved with curriculum development, such as a LP, is vital. We cannot trust our own science expertise, as the scope would either be too narrow, wide or ingrained with biases. The need for content experts provides a validity to our process of developing LPs. Established standards and curriculum guides, just like the *Benchmarks* (1993), *National Science Education Standards* (1996) and NGSS (2013), have employed the use of experts. However, we, as science educators, cannot minimize our role. Additional science pedagogy experts outside of our own developmental team are required to remove our own biases. By including the greater science education community, we model the development of LPs just as the aforementioned standards.

The impact of an expert-derived LP can help with the development of the accompanying SCLEs, activities, and definitions of for student conceptual gains. Having expert interviews create a base for included elements of the LP allowed for their input to dictate what should be included. When working with experts, you must make sure they are qualified. Looking at publication histories, memberships to national organizations, honors, and outreach efforts can help you identify experts. Given that LP development is an inaccurate science, having a model to rely upon provides some structure to a highly theoretical process.

However, a LP developmental team's expertise is just as important. Once the expert derivation through standards (i.e., NGSS) is complete, a development team must rely on their own knowledge and skills to flesh out the LP. SCLEs, activities, lessons, levels of knowledge, overall knowledge claims and pedagogy of the LP are determined by the team developing the LP. If we sit in isolation to develop such a robust model, how do we know it is complete? Developing an LP in seclusion is no better than teaching science in segregate units with no integration. A goal of LPs is to integrate units of science with learning of various concepts occurring simultaneously. We must do the same in the developmental process.

Limitations do exist with this development model. The methodology for expert-derived LP design is limited by the experts. Although the they provide the necessary support against the criticisms that theoretical LPs face, selection and recruitment is vital to the process. The dinosaur LP embedded in Earth and life sciences established a proposed best method for using dinosaurs as a "vehicle" based upon expert ideas. In this particular LP, there was a relatively consistent agreement amongst experts, but ideally more than two pedagogy experts and content experts would be interviewed. If experts had disparaging views, more experts would have needed to be amassed to provide reliability.

My goal of this study is to integrate the LP into a science teacher education course. The ideal course would be one that mixes pedagogy and content with a focus in Earth and life sciences. Preservice teachers would progress through the simulated grade-bands as the student, while the instructor would simulate the role of the teacher. Ultimately, a study to measure the pedagogical content knowledge (PCK) gains associated with a LP intervention designed for preservice teachers. The LP is developed based upon NGSS standards for K-12, but those same standards are the ones that preservice teachers must be able to teach. This LP meets Duschl, Maeng, and Sezen's (2011) recommendation for studying LPs in teacher training. By offering a simulated progression through grade-bands, preservice teachers will learn Earth and life science concepts in an integrated and progressive manner. Exemplar SCLEs in a 5E lesson plan format will afford preservice teachers the opportunity to experience lessons in the manner they should be teaching upon graduation.

Just like all developed LPs in the past (Metz, 2011; Plummer & Krajcik, 2010; Plummer et al., 2015; Smith, Wiser, Anderson, & Krajcik, 2006; Songer, Kelcey, & Gotwals, 2009; Steven, Delgado, & Krajcik, 2010), an ultimate goal for this LP on dinosaurs would be to get it into K-12 classrooms. Integrating it into experimental studies to measure the effectiveness of the proposed SCLEs coordinating is needed. Other studies need to follow this same methodology to determine the effectiveness of expert-derived LP development. Additional topics of science that are of high interest for students would be a recommended starting point for future LPs.

CHAPTER III

THE IMPACT OF A LEARNING PROGRESSION ON THE CONCEPTUAL KNOWLEDGE DEVELOPMENT OF PRESERVICE TEACHERS

Rationale

Teacher education frameworks of today provide a multitude of systems for preparing preservice teachers for their future classrooms. Undergraduate education courses, such as methods courses, can provide meaningful experiences for preservice teachers to help develop their pedagogical skills (Kelly, 2000). For future science teachers, an assortment of introductory level science courses not specifically designed for preservice teachers provides most of their content knowledge (Lyons et al., 2015). While some advancements have been made, many science teacher education programs still gamble on general undergraduate science content courses in biology, physics, chemistry, geology, astronomy, and other disciplines to provide the base of content knowledge. Education programs, in contrast, often focus on methods for teaching, with little recognition that teaching any content domain area also includes information and experiences about the structure of the domain knowledge and the methods of inquiry by which knowledge advances in that domain (Phenix, 1964). Conditions are still as they were described over 20 years ago when Lederman, Gess-Newsome, and Latz (1994) suggested that heavy reliance on college coursework for content knowledge is a fundamentally weak structure for preparing future science teachers.

Ball (2000) presented three problems directly related to content knowledge, which challenge those in teacher preparation programs charged with teaching preservice teachers how to teach science. The first challenge is preparing teachers with knowing what content material is fundamental to good teaching. The second challenge is preparing teachers familiar with the content materials how to access it in a useable manner. The third challenge is preparing teachers with opportunities to show them how to use content knowledge in practical, contextual ways. The preparation of teachers should not only focus on methods for teaching (Gess-Newsome & Lederman, 1993). Optimal preservice teacher preparation bridges the gap between content knowledge of various domains, pedagogy, and practical applications of this knowledge (Cochran, 1997; Nilsson & Loughran, 2013; Wallace & Loughran, 2012).

Santau, Maerten-Rivera, Bovis, and Orend (2014) state that “it is imperative for preservice elementary teachers to build deep and complex understanding of science content in order to teach it to their students through reform-based authentic inquiry” (p. 970). A strong focus on intertwining content knowledge in the scope of teacher education courses may lead to a higher sophistication of preservice teacher content knowledge. The *Next Generation Science Standards* (NGSS) call for pedagogy to include inquiry, problem-based investigations and engineering design (NGSS Leads States, 2013). However, college courses preparing science teachers are not usually instructed in this manner. The stereotypical college science course is in a lecture hall providing a diffusion of material that disengages the instructor from the students. Students are required to master content knowledge through visual and auditory learning methods practiced during lectures; and many students rely on rote memorization for mastery of knowledge. Sadly, many current college classrooms represent this disconnected model, which provides no help to preservice teachers who believe science is best taught by delivery of information. This method of teaching neither reflects the way science is done nor practiced by scientists. More desirable in modern K-12 science classrooms is for students to learn science as it is practiced by scientists.

Another desirable is that K-12 science students learn science in such a way that they can use their knowledge to understand aspects of the world in which they live. Objects and events occurring in the natural and designed world, by their nature, are interdisciplinary in context. Understanding how things work in the world requires scientific understanding that crosses traditional science domains and disciplines. The NGSS refer to science practices and crosscutting concepts as conceptual understandings that transcend all domains of science. Skills (i.e. analyzing data, developing scientific arguments, planning investigations) and crosscutting concepts (i.e., patterns, cause and effect, scale, proportion, quantity, systems, energy and matter, structure and function, stability and change) provide the tools for students to develop an understanding about the world that goes far beyond the memorization of facts. Using these skills and emphasizing crosscutting concepts provides teachers the opportunity to transform learning into a practical, student-centered, concept-driven, and “big-picture” style of learning.

Student-centered practices aimed at conceptual understanding in the K-12 classroom replace the traditional conception of the teacher as the disseminator of knowledge. Student-centered practices require teachers to facilitate learning, individualize instruction, and, whenever possible, allow students to seek and find their own paths to successful learning. New socio-cognitive perspectives of learning replace teaching practices aimed at individualized "mastery" with learning within situated contexts, recognizing the values of social learning through distributed cognition (Jonassen & Land, 2000). However, obstacles persist in K-12 classrooms (e.g., standardized testing) that would finally retire the old paradigm of rote content fact learning and promote student-centered conceptual learning (Darling-Hammond & McLaughlin, 1995). Education coursework that links theory to practice with instructors that model "good teaching" is desired (Darling-Hammond, 2006). To teach with new models of learning that emphasize conceptual understanding in science, preservice teachers need to be able to make connections between the various domain-specific pockets of knowledge they have previously acquired to appropriate pedagogical practices for the modern science K-12 classroom.

At this point in time, Ball's (2000) three problems remain regarding content knowledge for teacher preparation: (1) preparing preservice teachers to know the content material fundamental to good teaching; (2) preparing preservice teachers familiar with the content materials to access them a useable manner; and (3) preparing preservice teachers by showing them how to use content knowledge in practical, contextual ways.

Related Literature

Learning Progressions

A nonintegrated approach to conceptual learning that includes too many unnecessary details should be a method of the past (Fortus & Krajcik, 2011). An approach integrating teaching methods while learning science can solve multiple concerns about preparing preservice teachers to teach science. Combining science content and pedagogy systematically may be a potential solution to current concerns that K-12 learning be student-centered, experiential, interdisciplinary, and situated. Situated learning methods in preservice classes may be one possible solution to increasing low science pedagogical content knowledge (PCK) concerns (Ball, 2000). In other words, preservice teachers who learn science as they should be teaching it in their own classrooms should have an easier time transferring what they learn in their university classes before they assume their first teaching positions.

One potential method to improve PCK of preservice science teachers could be the inclusion of learning progressions (LPs) in science content-focused teacher education courses. Learning progressions (LPs) were developed as a solution to the curriculum dilemmas of aligning instruction across grade levels and integrating concepts in science towards better conceptual understanding of big ideas (Corcoran et al., 2009). At the conceptual root of LP development was a greater sophistication and mastery of science topics over time (Corcoran et al., 2009; Plummer et. al, 2015). The National Research Council (NRC, 2007) provided an operational definition for LPs in *Taking Science to School.*

> Learning progressions in science are empirically grounded and testable hypotheses about how students' understanding of, and ability to use, core scientific concepts and explanations and related scientific practices grow and become more sophisticated over time, with the appropriate instruction. (p.8)

Over the past few years, researchers have been trying to legitimate LPs as reliable curriculum structures that, over time, progress students' development of deep conceptual understanding of thematic topics across science domains. Corcoran, Mosher, and Rogat (2009) affirm that LPs should provide vertically aligned concept-based instruction, while others (e.g., Mosher, 2011; Wiser, Smith, & Doubler, 2012) contend that LPs should allow for teachers to assess conceptual development over time. LPs have shown to be effective in K-12 schools in multiple studies (Metz, 2011; Plummer & Krajcik, 2010; Plummer et al., 2015; Smith, Wiser, Anderson, & Krajcik, 2006). Furthermore, LPs can be a beneficial tool for assessing the development of conceptual knowledge over a set amount of time (Mosher, 2011; Wiser, Smith, & Doubler, 2012).

According to current recommendations, five elements must be present in well-developed LPs: (1) clear end points around a central theme, (2) well-defined core ideas and practices, (3) operationally defined levels of knowledge and achievement (i.e., adequate intermediate, advanced), (4) learning activities accompanying these operational definitions, (5) assessments developed to measure student understanding. The first two components trace back to strand maps developed for the *Atlas for Science Literacy*, which provided a vertical alignment of topics in the *Benchmarks for Science Literacy* within a defined scientific theme (American Association for the Advancement of Science [AAAS], 1993, 2001, 2007). The *Atlas of Science Literacy*'s strand map designs (AAAS, 2001; AAAS, 2007) visually represents how topics over time can be integrated in science instruction. However, the strand maps lack learning activities, defined levels of understanding, or clear end points for the learning (Duschl, Maeng, & Sezen, 2011; Mosher, 2011; Wiser, Smith, & Doubler, 2012). The other three components are specific to LPs and separate LPs from strand maps. These components go beyond curriculum alignment and mere suggestions of what to learn. LPs propose pathways showing students' learning from a progression of topics in a given time frame, while incorporating assessment in the process (Duschl, Maeng, & Sezen, 2011). LPs typically provide a more sophisticated manner of organizing learning activities over a determined span of time (i.e., unit of study, grade-level, grade-bands; Duschl, Maeng & Sezen, 2011).

The inclusions of LPs in coursework for preservice teachers would allow preservice teachers to learn in a student-centered manner. LPs could increase PCK by integrating previously learned science topics and connecting the concepts across domains of knowledge. In *How People Learn: Brain, Mind, Experience and School*, Bransford, Brown, and Cocking (2000) state "environments that are learner-centered attempt to build on the strengths, interests, and needs of learners" (p.192). Modeling science teacher education with LPs that simulate student-centered learning environments (SCLEs), such as the ones preferred for learning science, have the potential to increase the PCK of preservice teachers and their own content knowledge. At this point in time, however, the use of “LPs in actual teaching and planning is understudied” (Duschl, Maeng, & Sezen, 2011).

Scaffolding learning around SCLEs would allow teachers to facilitate knowledge acquisition through activities that build conceptual knowledge (Land & Hannafin, 2000; Land, Hannafin, & Oliver, 2012). In preservice teacher preparation, SCLEs could build epistemological and pedagogical foundations by modeling proper reformed-based practices. Also, peer interactions in courses in student-centered coursework could lead to socio-cognitive changes. Preservice teachers should not be constrained to a disembodied, objective learning environment; instead, experiential learning practices are suggested for the promotion of authentic science learning and future practices (AAAS, 2000; Bybee et al., 2006; NGSS Leads States, 2013).

Several researchers theoretically have linked learning science in a traditional, diffusive manner via lecture and the development of “traditional beliefs” in the classroom, thus building limited PCK for preservice teachers to access in their future teaching (Hancock & Gallard, 2004; Oleson & Hora, 2014; Tsai, 2002). Modeling “good teaching” through practice and preference of hands-on learning are recommendations of prior studies (Darling-Hammond, 2006; Hancock & Gallard, 2004).

Concept Mapping

Development in cognitive theory led Ausubel (1968) to develop hierarchical memory structures, the precursor to modern day concept mapping. Novak worked with Ausubel on cognitive theory and established the groundwork for his work in the 1980s on concept maps (Ausubel, Novak, & Hanesian, 1978). Novak and Gowin (1984) are the pioneers for concept mapping and make the case for concept maps as assessment tools. According to Novak and Gowin's conventions, concept maps are hierarchically constructed and include user-developed words to link individual concepts placed within the map, either adjacent or across the proposed concept map. Concept maps can be used as an appropriate and functional assessment for SCLEs (Novak, 1991; Novak, 2010).

A few operational definitions based on Novak and Gowin's (1984) work may help in understanding the terminology of concept maps. *Propositions* refer to the relationship between two concepts, often identified by words connected by a line. The proposition is placed as a word or phrase written on the line. *Hierarchy* refers to the levels of construction within the map. More general or abstract concepts are placed at levels higher on the map than more specific concepts placed lower on the map. *Crosslinks* refer to connections between concepts in different domains on the concept map. *Crosslinks* provide insight into how the developer of the concept map interrelated topics appearing in different sectors of the concept map, representing connections between concepts not commonly linked together.

Scoring concept maps supports the notion of inter-domain knowledge connections as higher-order thought. *Propositions* between concepts considered valid are scored with one point. Each valid level of the hierarchy is scored with five points. *Crosslinks* have two different methods for scoring. *Nonsignificant Crosslinks* are defined as those exhibiting no synthesis between concepts, while valid crosslinks signify meaningful, logical, and often creative connections between concepts in unrelated levels of *Hierarchy* or domains. *Nonsignificant Crosslinks* are worth two points, while *Valid*

Crosslinks are worth ten points. Such disparaging scoring between a proposition and crosslink (i.e., one point versus ten points) connotes higher cognitive skills associated with developing relationships between unconnected portions of a concept map. Also, the scorer of the map awards points only recognizes the validity of the *Proposition*, *Hierarchy* level or *Crosslink* developed by the map creator. This justifies the conceptual understanding of the map developer by making no assumptions of what was intended, thus only scoring what was submitted.

Activity Theory

Activity theory provides an evolving conception of learning that blends SCLEs with the notion of "doing is learning" (Engeström & Miettinen, 1999; Jonassen, 2000). Jonassen and Rohrer-Murphy (1999) suggested activity theory as a support for constructivist approaches to learning and teaching through the use of student-centered, activity-based engagement. Social aspects of learning are also supported with activity theory, as these authors represented the entire activity system as modeling a distribution of knowledge across learners and into the objects they create as part of the system. Expanded from Vygotsky, Engeström (1987) extended activity theory to include more than just mediating artifacts between the subject (i.e., the learner) and the object. Engestrom (2001, 2014) added multiple additional components to the system, including the rules governing the system, division of labor, the community engaged in the system and the tools manipulated. These components have tangential relationships with one another and interact as a part of the activity theory system. Jonassen applied the theory to student-centered learning and created subsystems within the larger model (Jonassen &

Rohrer-Murphy, 1999; Jonassen, 2000; Jonassen & Easter, 2012). Rather than objects being the conclusion of the theoretical system as Vygotsky established, Engeström and Jonassen have emphasized that outside lies the outcomes of the entire activity system.

Role of the Literature in Framing the Study

Activity theory, concept maps, and learning progressions form the conceptual foundation framing this study. The intervention for this study was an interdisciplinary, situated, K-12 LP on dinosaurs I developed for a preservice science content course taught in the College of Education. In the sense of activity theory, the Dinosaur LP was the activity system in which preservice teachers engaged as learners, engaging in dinosaur-related SCLEs at four grade level bands. In this study, the Objects were the concept maps developed by the preservice teachers, which I used to measure students' levels of conceptual understanding before and after their engagement. The Outcome of this activity system was preservice teachers' PCK. While concept maps alone did were not the only measure of preservice science teacher's PCK, I used this assessment tool, in particular, to provide insights regarding the knowledge construction and conceptual understanding driving preservice teachers' development of PCK within the LP on dinosaurs.

Research Questions

PCK development in preservice teachers is a paramount concern for science education. Part of PCK development is the conceptual and domain knowledge acquisition of preservice teachers. However, as previously referenced (Lederman, Gess-

Newsome & Latz, 1994), traditional collegiate science courses are not the solution. The research questions for this study referred to a non-traditional, collegiate science course integrating Earth and life science concepts, pedagogy, and their classroom applications. More specifically, the research questions were related to preservice teachers' PCK development as a result of their engagement in an LP on dinosaurs. This investigation broke new ground, as the use of LPs with teachers has been understudied (Duschl, Maeng & Sezen, 2011) and no studies have specifically targeted the use of LPs with preservice teachers. Three research questions guided the design of this study:

1. How do preservice teachers' conceptual understanding of Earth and life science concepts change after a learning progression experience?
    a. How does the conceptual knowledge of individuals shift after the LP?
    b. How does the conceptual knowledge of groups shift after the LP?
2. What patterns of similarities and differences are observable in comparisons between scientific domains in pre- and post-LP concept maps?
3. What conceptual knowledge relationships exist between preservice teachers' individual concept maps and group maps?

Methods

In another study, I led a team of researchers working with paleontologists and science education experts to craft the LP with dinosaurs as a theme. Johnson, Alexander, Spencer, Leibham, and Neitzel (2004) found that the top science interests of preschool-aged students entering school was dinosaurs, even though these prehistoric beasts are not referenced in the modern curriculum guide (NGSS Leads States, 2013). Thomas Holtz, one of the expert paleontologists interviewed during the development of the LP, stated “dinosaurs are obviously the one that attracts the most people” when he discussed his development of an entry-level geology course at the University of Maryland (Holtz, 2016). Holtz’s course included dinosaurs for the purpose of enticing student enrollment.

The purpose of this study was to see whether an LP could be used in science education coursework to increase the PCK of preservice teacher, focusing on the conceptual and domain understanding of preservice teachers during PCK development. Knowing the high levels of interest in dinosaurs spanning K-12 students and beyond, I chose the theme of dinosaurs as the focus of the LP for the study. I designed a simulated LP, which required preservice teachers to take learner roles as if they were K-12 students. I designed the dinosaur LP to simulate learning activities for the four major grade bands (i.e., K-2; 3-5; Middle School; High School) as designated by the NGSS (2013). I implemented concept maps to measure preservice teachers’ conceptual and domain understandings and PCK. Choosing an explanatory mixed methods study design, I used quantitative data analyses to determine significant differences between my students’ pre- and post-concept maps; and subsequent qualitative data analyses to further explain the conceptual thought processes and voices of preservice teachers.

Participants

The study was conducted with two course sections of preservice teachers enrolled in a science content course delivered by the science education cognate group at a large research university in the southern United States. The participant pool consisted of sixty-nine (n=69) preservice teachers. The sample was a convenient sample that included a multitude of certification concentrations (i.e., Early Childhood through Grade 6; Grades 4-8 Math/Science; Grades 4-8 English Language Arts/Social Studies). I collected individual data from participants as group data from participants as members of a group. I regarded group data as usable if a majority of preservice teachers in the group consented to data collection. Any group with two or more nonconsenting students was excluded from both individual and group analysis.

Design

I chose an explanatory mixed methods study (Creswell & Plano Clark, 2011) for this study, using both quantitative and qualitative data to identify significant findings. Preservice teachers' conceptual understandings referred to their use of 27 specific concepts validated by scientists and science educators in an earlier study. Preservice teachers placed copies of these basic concepts on a blank piece of paper to create their concepts maps, which they initially created as individuals and then members participating within a group.

My choice of this research design allowed for the simultaneously collection of two data sets within one data collection cycle. The explanatory design also supported my management of a large data set while allowing for the analysis of data both quantitatively and qualitatively. Additionally, I chose an explanatory mixed method design to further explain students' placements by capturing the participants' voices and conceptual thought process. A closer examination into trends in the group concept maps provided evidence for explanations of significant quantitative findings. In the light of the theoretical grounding of the study in activity theory (Jonassen & Easter, 2012), I was especially interested in the group concept maps to determine the extent of which distributed cognition played a role in individual's PCK development.

Intervention of the Learning Progression

Preservice teachers engaged in the simulated Dinosaur LP embedded within in a six-week study I designed to focus specifically on PCK growth. During the first week of the study and prior to data collection, I reviewed with preservice teachers the basics of concept maps using Novak and Gowin's (1984) methods for constructing hierarchical concept maps. Later in that first week, I collected individual and group concept maps. Preservice teachers then engaged in the dinosaur-centered LP for four weeks. In the sixth week and after the completion of the simulated LP, I collected individual and group concept maps once again. In conjunction with rules for concept mapping, I scored concept maps using Novak and Gowin's scoring methods. Neither formal rubrics nor criterion concept map was used in scoring.

Data Collection

Participants of the study completed individual and group concept maps using 27 core concepts previously identified about Earth and life science principles. With dinosaurs as a central theme, a validation team identified the 27 concepts from the underlying content of the LP. The 27 concepts coordinated with four domains of scientific understanding in Earth and life sciences. In the concept maps students constructed before the LP, preservice teachers arranged the terms individually, first. I gave concept terms to preservice teachers on strips of paper. Preservice teachers arranged concepts on a large sheet of manila paper. I provided stickers of the concepts to each student for final placement on the map. After individual maps were constructed, the preservice teachers worked with other classmates in groups of four to construct their group maps. The groups established at this time were the groups who worked together as they engaged in all of the SCLES of the LP for the remainder of the study.

Each of the four weeks of the simulated LP focused on a different grade band (i.e., K-2, 3-5, Middle School and High School). In my design of the LP, I infused the 27 concepts throughout the entire four-week experience. Upon completion of the simulated LP on dinosaurs, preservice teachers once again constructed concept maps and used the same procedures and terms established during the pre-LP concept mapping experience.

Results

I used Novak's scoring convention to score all pre- and post-LP individual concept maps for both individuals and groups. I measured similarities and differences in the individual maps using paired samples t-tests (n=69) and Wilcoxon-signed ranked tests for group maps due to a smaller sample size (n=18). A colleague and I scored concept maps and calculated Cohen's Kappa to yield an interrater reliability of 0.921 (Cohen, 1960).

Quantitative Analysis of Individual and Group Concept Maps

Tables 4 and 5 show frequency scores prior to and after the LP intervention for individual and group scores, respectively. Preservice teachers' scores ranged from a 1 to 69 pre-intervention and 12 to 85 post-intervention for individual concept maps. Group scores had a much higher ceiling for post-intervention scores, but were actually lower for pre-intervention group-developed concept maps.

Table 4

Individual Concept Map Overall Score Quartile Range for Pre- and Post-Intervention (n=69)

Quartile	Pre-concept map scores range	Pre-overall score frequency	Post-concept map scores range	Post-overall score frequency
1	1 - 14	18	12 - 30	18
2	15 - 22	16	31 - 39	18
3	23 - 30	17	40 - 52	16
4	31 - 69	18	53 - 85	17

Table 5

Group Concept Map Overall Score Quartile Range for Pre- and Post-Intervention (n=18)

Quartile	Pre-concept map scores range	Pre-overall score frequency	Post-concept map scores range	Post-overall score frequency
1	9 - 18	5	38 - 47	4
2	19 - 25	4	48 - 64	5
3	26 - 42	4	65 - 81	4
4	43 - 59	5	82 - 109	5

Table 6 compares individual post-intervention scores to group post-intervention scores. The average scores were higher for each quartile, and the overall range had a higher low-end and top-end score for group maps. A comparison of the fourth quartiles of post-intervention individual and group maps highlighted the impact of distributed cognition between groups. The highest individual score (85) was nearly the lowest fourth quartile score (82) for group concept maps.

Comparing overall scores in a descriptive manner can highlight changes in conceptual understanding that occurred after preservice teachers' experience with the LP. I extended these findings with a further analysis to examine what actually was changing in the scoring. In addition to overall scores, I took a closer look into scoring categories (i.e., number of concepts used, valid propositions, levels of hierarchy, nonsignificant and valid crosslinks). I paired pre- and post-intervention concept map overall scores and scoring categories (i.e., number of concepts used, valid propositions, levels of hierarchy, nonsignificant and valid crosslinks) for both individuals and groups.

Table 6

Quartile Comparison of Post-Intervention Individual (n=69) *and Group* (n=18) *Scores*

	Individual post-intervention scores				Group post-intervention scores			
Quartile	Mean	SD	Range	Frequency	Mean	SD	Range	Frequency
1	23.0	5.4	12 - 30	18	43.0	3.9	38 - 47	4
2	34.9	3.0	31 - 39	18	60.0	4.5	48 - 64	5
3	44.7	3.2	40 - 52	16	77.0	5.4	65 - 81	4
4	67.2	8.8	53 - 85	17	98.2	7.8	82 - 109	5

Table 7

Paired t-tests Analyses of Individual Concepts Maps After Learning Progression Intervention

Paired sample	Mean difference	Std. deviation	*t*	*df*	Sig (2-tailed)
Pre-No. Concepts - Post-No. Concepts[a]	2.5 ***	2.6	7.758	68	.000
Pre-Proposition - Post-Proposition	6.0***	5.4	9.109	68	.000
Pre-Hierarchy - Post-Hierarchy	3.9***	4.3	7.601	68	.000
Pre-Nonsig Crosslink- Post-Nonsig Crosslink[b]	0.5	2.4	1.811	68	.074
Pre-Valid Crosslink - Post-Valid Crosslink	7.1***	13.4	4.400	68	.000
Pre-Overall - Post-Overall	7.5***	15.9	9.149	68	.000

[a] No. Concepts refers to the number of concepts that a participant attempted to use on individual concept map.

[b] Nonsig refers to nonsignificant crosslinks in concept maps.

Table 7 shows the results of paired t-tests for individual concepts maps. As a class, overall pre-intervention concept maps scores (M=24.5, SD=13.2) significantly increased post-intervention (M=42.0, SD=17.3). Overall concept map scores yielded an average gain of 17.5 (SD=15.9), which was statistically significant (p<.001, t=9.15). Preservice teachers were able to use more concepts post-intervention on individual concepts maps at a statistically higher frequency (p<.001, t=7.76). Valid proposition use increased by an average of 6 (SD=5.4) and was significantly higher on post-intervention concept maps (p<.001, t=9.11). Hierarchy increased by nearly one scoring level from pre- to post-intervention concept maps (M=3.9, SD=4.3) and was found to be significantly higher after the LP intervention (p<.001, t=7.60). for the class. Preservice teachers' valid crosslinks attributed for 7.1 more points per map (SD=13.4) for the class post-intervention and the ability to link different domains of scientific knowledge via valid crosslinks was significantly higher (p<.001, t=4.40).

In the implementation of the Wilcoxon Signed Rank Test for analysis of group concept maps, I found results indicating that the same areas were also significant. Once again, no significant difference occurred between nonsignificant crosslinks, while all other areas were significantly higher (see Table 8) post-intervention. Use of concepts (p<.05, Z=2.04), valid propositions use (p<.01, Z=3.15), levels of hierarchy (p<.01, Z=3.14), valid crosslinks (p<.01, Z=3.28) and overall concept map score (p<.01, Z=3.48) were significantly higher after preservice teachers' experience with the Earth and life sciences LP on dinosaurs.

Table 8

Wilcoxon Signed Rank Test Analyses of Group Concepts Maps after Learning Progression Intervention

Paired sample	*n*	*Z*	Sig (2-tailed)
Pre-No. Concepts - Post-No. Concepts[a]	18	2.041*	.041
Pre-Proposition - Post-Proposition	18	3.150**	.002
Pre-Hierarchy - Post-Hierarchy	18	3.143**	.002
Pre-Nonsig Crosslink - Post-Nonsig Crosslink[b]	18	0.144	.886
Pre-Valid Crosslink - Post-Valid Crosslink	18	3.283**	.001
Pre-Overall - Post-Overall	18	3.479**	.001

[a] No. Concepts refers to the number of concepts that a group attempted to use on individual concept map.

[b] Nonsig refers to nonsignificant crosslinks in concept maps.

A Closer Explanation of Group Concept Map Trends

A closer look into the trends on group maps allowed me to understand more about why the changes occurred. I had observed higher overall scores and the same significant differences for scoring categories and overall scores in both individual and group concept maps. Due to this observation, I decided to further investigate details of the group concept maps. Every group contained three or four preservice teachers and remained constant for the construction of pre- and post-LP concept maps. These groups were made of peers that worked together through each of the four grade bands of the learning progression.

Domain level knowledge refers to the primary categories established in the concepts maps. I and another science education researcher recorded the first order of hierarchy for all group maps, both pre- and post-intervention. We coded the concepts listed in this layer of concept map construction, identified in Table 9 as Primary Domain(s). We compared other data for each group to include changes in number of concepts used as domains, levels of hierarchy, valid crosslink usage, percent change in score and overall score. When we focused on concepts chosen as Primary Domains, I found 10 of 18 groups had more Primary Domain categories across the top of their hierarchical concept maps, post-intervention. After the completion of the LP, nine of the groups used more Primary Domains resulting in high map scores. Out of the remaining group, five groups had the same number of Primary Domains and three groups used less Primary Domains on their final concept map.

Table 9

Change in Number of Primary Domain(s), Score, Hierarchy, and Valid Crosslink Usage (n=18)

	Pre-concept map		Post-concept map		Change			
Group	Primary domain(s)[a] (n)	Score	Primary domain(s) (n)	Score	Domain change	Score change (%)	Hierarchy change	Valid crosslink change
1	Geology (1)	30	Ecology, Geology (2)	95	+1	216.7	+1	+5
2	Life Cycles, Habitat (2)	25	Geology, Natural Selection, Genetics (3)	79	+1	216.0	+2	+4
3	Evolution (1)	18	Evolution (1)	79	0	338.9	+4	+3
4	Ecology, Geology (2)	47	Ecology, Geology, Evolution (3)	109	+1	131.9	-1	+6
5	Genetics, Geologic Time (2)	23	Ecology, Geologic Time, Life Cycles (3)	64	+1	178.3	+2	+3
6	Ecology, Geology (2)	27	Ecology, Geology, Genetics (3)	103	+1	281.5	+3	+6
7	Ecology, Geology, Competition (3)	59	Ecology, Geology (2)	38	-1	-35.6	-1	-1
8	Ecology, Geology (2)	55	Ecology, Geology (2)	95	0	72.7	0	+3
9	Ecology, Geology (2)	24	Evolution (1)	42	-1	75.0	+2	+2
10	Ecology, Geology (2)	34	Ecology, Geology, Life Cycles (3)	69	+1	102.9	+1	+1
11	Ecology, Geology (2)	18	Ecology, Geology (2)	47	0	161.1	+3	0

Table 9 continued

	Pre-concept map		Post-concept map		Change			
Group	Primary domain(s)[a] (n)	Score	Primary domain(s) (n)	Score	Domain change	Score change (%)	Hierarchy change	Valid crosslink change
12	Ecology, Geology (2)	45	Ecology, Geology, Life Cycles (3)	45	+1	0.0	+3	-1
13	Ecology, Geology, Genetics (3)	42	Ecology, Geology, Genetics (3)	81	0	92.8	+1	+2
14	Ecology, Geology, Evolution (3)	51	Ecology, Geology, Evolution, Genetics (4)	53	+1	3.9	+1	-1
15	Ecology, Geology (2)	9	Ecology, Geology, Evolution, Genetics (4)	60	+2	566.7	+1	+3
16	Ecology, Geology, Life Cycles (3)	22	Ecology, Geology, Life Cycles (3)	59	0	168.2	0	+3
17	Ecology (1)	16	Ecology, Geology (2)	64	+1	300.0	+2	+2
18	Growth, Fossils, Inheritance, Habitat, Survival (5)	18	Ecology, Geology, Evolution (3)	89	-2	394.4	+3	+4

[a] Primary Domain refers to the initial concept(s) a participant used first in concept map construction.

Although the number of Primary Domains was interesting, the real mystery involved uncovering how categorizing conceptual knowledge of teachers affected their map construction and overall score.

The concepts used for the Primary Domains were intended by the LP development team to be the broadest concepts provided to the preservice teachers during concept map construction. The domain concepts of Ecology, Evolution, Genetics & Organisms, and Geology were intended to be the big four areas of concentration. During the development of the LP on dinosaurs, these four concepts were the four Primary Domains of knowledge identified by the research team. Student groups able to determine at least Ecology and Geology to be two of the most important concepts and use them as Primary Domains during construction saw higher scores on both pre-intervention and post-intervention maps. Groups that also found Evolution and/or Genetics & Organisms also achieved higher scores on concept maps.

When I focused on the 16 of 18 groups that improved their overall scores, 9 groups added one or more Primary Domains. Overall scores for 8 of these groups increased by more than 100% and all of these groups had more valid crosslinks present on their post-intervention concept maps. Seven of the groups also had more levels of hierarchy after the LP. The two groups, Group 12 and Group 14, with decreases in valid crosslinks, also had a very minimal positive or no change in their overall score. The trend indicates that after the LP on dinosaurs that emphasized all of the concepts present for concept mapping, groups that were able to organize information into more domains (e.g., 4 domains as a maximum). Additionally, groups added more meaningful crosslinks to interrelate concepts of different domains. This trend supports the design of the LP as an integrated curricular design for life and Earth science concepts.

Five groups (Groups 3, 8, 11, 13, 16) remained constant with the number of Primary Domains during their post-intervention concept mapping. All of these groups had increases in their overall scores. Group 11 was the only group not using more valid crosslinks, but this group did have an increase in 3 levels of hierarchy. Group 3 was the most unique, due to their construction of their entire map under the umbrella of Evolution as their only Primary Domain. However, this group still saw a large increase in overall score, primarily due to better proposition use and hierarchical structure. Three groups decreased their Primary Domain categories (Groups 7, 9 and 18). Group 9 and Group 18 both saw increases in their scores due. Group 9 had Ecology and Geology as Primary Domains on their pre-intervention concept map, but consolidated their map under Evolution, much like Group 11.

Group 18 was one of the most interesting pre- to post-intervention shifts in knowledge construction. All of their original 5 terms for Primary Domains in the pre-intervention map were more specific concepts. Due to this, they had low levels of hierarchy and no valid crosslinks in their original group developed map. Their post-intervention map was constructed using three of the most inclusive concepts, Ecology, Evolution and Geology, as their Primary Domains. This group also increased their levels of hierarchy, which indicated more organization of their conceptual understandings. Four valid crosslinks between their three Primary Domains demonstrated their ability to connect concepts across domain levels of knowledge.

Post-intervention concept maps for the 18 groups only included one group (Group 7) with a decrease in overall score and one group (Group 12) that remained the same. Group 7 had a 35.6% lower score on their final concept map, which was primarily due to have one less layer of hierarchy and one less valid crosslink. Those two decreases in construction were worth 15 points of the 21 points that Group 7 failed to match from their first distributive-designed concept map. Group 12 was an outlier in comparison to the other groups that added more levels of Primary Domains.

I noted four major trends in post-intervention group concept map construction, represented in Table 9. (1) Groups identifying Ecology and Geology as important terms early in map construction were better able to organize their conceptual understandings with resulting higher overall scores. (2) Identifying key concepts as the most general (i.e., Ecology, Evolution, Geology, Genetics & Organisms) allowed groups to better arrange more specific concepts later in map construction with additional layers of hierarchy. (3) After experiencing the learning progression, preservice teachers were able to create more valid crosslinks between domains of knowledge. (4) Three or four Primary Domains allowed for higher overall scores and positive gains in conceptual understanding.

Use of Concepts

Both individual and group concept maps were significantly more complex and better constructed after preservice teachers' engagement in the LP on dinosaurs. Furthermore, their ability to identify and integrate key concepts improved in life and Earth science fields of study. However, a purely quantitative analysis of class performance did not identify where preservice teachers had made the largest improvements or what foundational knowledge the preservice teachers had previously acquired. To better understand which concepts where used to make valid propositions, the research team went back to count all group-developed concept maps for each concept. Concept use was only deemed valid if a concept was connected to another by a valid proposition. The findings were arranged as a whole, rather than separated by individual groups. Table 10 compares the collective use of each of the 27 concepts to indicate the percentage of change in concept use from pre- to post-LP concept maps. Using the concept of Behaviors, for example, the concept was used 4 times before and 24 times after the LP, for a valid use change of 500.0%. In comparison, the concept of Rock Layers/Strata was used 30 times before and 31 times after preservice teachers' engagement with the LP, indicating a change of only 3.3%.

Table 10

Change in Valid Use of Collective Class Concept Terms after Learning Progression Intervention

Concept	Pre-concept map	Post-concept map	Valid use change (%)
Behaviors	4	24	500.0
Resources	5	30	500.0
Extinction	7	25	257.1
Traits	11	32	190.9
Structure & Function (Morphologies)	11	29	163.6
Ecology	8	21	162.5
Evolution	14	35	150.0

Table 10 continued

Concept	Pre-concept map	Post-concept map	Valid use change (%)
Genetics & Organisms	11	27	145.4
Growth	11	27	145.4
Mutations	12	27	125.0
Inheritance	17	36	111.8
Evidence	10	21	110.0
Predator-Prey Relationships	16	33	106.3
Geologic Time	17	35	105.8
Habitat	12	30	150.0
Life Cycles	16	32	100.0
Plate Tectonics	14	24	71.4
Survival	19	31	63.2
Habitat	12	30	150.0
Diversity	24	39	62.5
Reproduction	28	42	50.0
Competition	23	34	47.8
Geology	14	20	42.9
Natural Selection	24	33	37.5
Environmental Change	28	36	28.6
Fossils	26	31	19.2
Adaptations	26	30	15.3
Rock Layers/Strata	30	31	3.3

Concepts with the largest valid use change were terms that were improperly used or not used on pre-intervention concept maps. Correct use of Behaviors (4), Resources (5), Extinction (7) and Ecology (8) was infrequent and did not reach double digit valid usage for 18 group concept maps. However, these four concepts, in addition to Traits and Structure & Function (Morphologies) accounted for the six highest valid use changes with 2.5 times more valid concept usage on post-intervention concept maps. Nine concepts including Life Cycles, Geologic Time, Predator/Prey Relationships, Evidence, Inheritance, Mutations, Growth, Genetics & Organisms, Habitat and Evolution, were all validly used at least twice in post-intervention maps. Geologic Time was the only Earth science-based concept out of the 16 most improved concepts. However, this does not mean the LP was ineffective in improving conceptual understandings of Earth science material for preservice teachers. Preservice teachers used Earth science terms in a valid manner more frequently on pre-intervention maps than the life science concepts. Earth science topics were better understood by this cohort of preservice teachers, thus valid use change was not as drastic as some of the life science concepts. Overall, all concepts were used to create more valid propositions on concept maps after the learning progression.

Distributed Cognition

Jonassen's activity theory model identifies that knowledge is distributed between different systems and across all learners (Jonassen, 2000). With the LP and design for this study rooted in activity theory, I decided to make a closer examination of the role of distributed cognition. I examined group maps to better comprehend the role that distributed cognition played prior to and after the LP intervention. Two categories for analysis were formed to examine the role of distributed cognition during the LP and concept mapping. The first category was Group Mean, which referred to a mean of individual concepts maps for a particular group. Group Mean scores represent the average of concept map scores developed by individual members of a group, either pre- or post-intervention. This average was compared to group-developed concept map scores, which were the maps that were constructed as a group without the use or access to previously constructed individual maps.

Table 11 displays the results between pre-intervention Group Mean and Group Developed concept map scores. Only the Number of Concepts ($p<.001$, $Z=3.72$) and Proposition ($p<.01$, $Z=2.61$) use were found to be statistically significant. Levels of hierarchy, crosslinks and overall concept map scores were not statistically different. This indicates that prior to preservice teachers experiencing the LP, distributed cognition did not significantly affect map construction beyond a single concept's relation to another concept. Preservice teachers were also able to use more of the concepts when working with a group than alone.

Table 11

Wilcoxon Signed Rank Test Analyses for Pre-Intervention Group Mean to Group Developed

Paired sample	*n*	*Z*	Sig (2-tailed)
Avg. No. Concepts - Group No. Concepts[a]	18	3.724***	.000
Avg. Proposition - Group Proposition	18	2.605**	.009
Avg. Hierarchy - Group Hierarchy	18	0.699	.485
Avg. Nonsig Crosslink - Group Nonsig Crosslink[b]	18	0.078	.938
Avg. Valid Crosslink - Group Valid Crosslink	18	0.453	.651
Avg. Overall - Group Overall	18	0.196	.845

[a] No. Concepts refers to the number of concepts that a group attempted to use on individual concept map.

[b] Nonsig refers to nonsignificant crosslinks in concept maps.

Table 12

Wilcoxon Signed Rank Test Analyses for Post-Intervention Group Mean to Group Developed

Paired sample	*n*	*Z*	Sig (2-tailed)
Avg. No. Concepts - Group No. Concepts[a]	18	3.635***	.000
Avg. Proposition - Group Proposition	18	2.678**	.007
Avg. Hierarchy - Group Hierarchy	18	3.062**	.002
Avg. Nonsig Crosslink - Group Nonsig Crosslink	18	0.240	.810
Avg. Valid Crosslink - Group Valid Crosslink[b]	18	2.559*	.011
Avg. Overall - Group Overall	18	3.245**	.001

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[a] No. Concepts refers to the number of concepts that a group attempted to use on individual concept map.

[b] Nonsig refers to nonsignificant crosslinks in concept maps.

The comparison between Group Mean versus Group Developed offered interesting results. The results reveal that distributed cognition played a role in the activity system between these 18 groups. Group Developed scores were significantly higher for Number of Concepts ($p<.001$, $Z=3.64$), Proposition ($p<.01$, $Z=2.68$), Hierarchy ($p<.01$, $Z=3.06$), Valid Crosslink ($p<.05$, $Z=2.56$) and Overall Score ($p<.01$, $Z=3.25$) categories. The only nonsignificant difference was for nonsignificant crosslink usage. Not to be confused with individual or group pre/post scores in Table 7 and Table 8, respectively, Table 12 shows significant difference between only post concept maps. The comparison is between Group Mean versus Group Developed. Pre-intervention concept maps (Table 11) and post intervention concept maps (Table 12) were compared separately.

Discussion

The specific, targeted use of a LP for preservice teachers offers a multitude of learning opportunities. The LP was initially to be developed for use in K-12 classrooms. However, with recommendations to study how LPs could be used with teachers (Duschl, Maeng, & Sezen, 2011), a new method for preservice teacher instruction was open for science education coursework (Mosher, 2011; Wiser, Smith, & Doubler, 2012). The use of dinosaurs as a thematic unit throughout the LP allowed preservice teachers to engage in learning through a vehicle that has not been explicitly stated in the curricular standards (NGSS Leads States, 2013). Also, by progressing from a first-grade to a third-grade to middle school and, finally, high school biology, preservice teachers experienced the vertical alignment across domains of science content. This sequence or "learning progression," allowed the preservice teachers to witness how disjointed topics could be taught simultaneously. Using concept maps as a summative assessment tool offered me the chance to analyze conceptual gains that affect PCK development of preservice teachers.

Preservice teachers showed statistically significant higher conceptual thought after their experience with a LP. While *Nonsignificant Crosslinks* were never found to have a statistical significance in any analysis, this finding is still substantial. This finding indicates that preservice teachers' attempts at *Crosslinks* between differing domains of science resulted in valid connections. Overall, the examination of preservice teachers' concept maps led me to conclude that preservice teachers were better able to conceptualize science concepts after their engagement in the simulated LP.

Furthermore, group interaction played a large role in utilizing LPs in preservice teacher education. Preservice teachers were able to collaborate as team during inquiries and assessments with the integration of activity theory (Engeström, 1987; Jonassen & Land, 2000), SCLEs (Land & Hannafin, 2000; Land, Hannafin, & Oliver, 2012) and more authentic science practices (Bybee et al., 1995; Mosher, 2011) into the LP developed specifically for them. This incorporation of the group aspect to the research design added another layer to the potential benefit that LPs can have for preservice science teachers. I was not surprised to find that a LP developed specifically for this particular group resulted in significant conceptual gains affecting their continuous PCK development. However, the increased levels of conceptual gains preservice teachers experienced by incorporating a distributed cognition component into assessment had an even more significant outcome for the overall conceptual knowledge growth in preservice teachers' PCK (Engeström & Miettinen, 1999; Bell & Winn, 2000). Not only did preservice teachers benefit conceptually from group work, but the integration of group roles allowed preservice teachers to experience how SCLEs and assessments with group components could be important in learning. This finding indicates that preservice teachers' intentions to include group activities in their own planning may increase, if they are given the time to reflect about the lessons they encountered in the LP.

The use of LPs in teacher education provided preservice teachers the opportunity to interrelate concepts of different targeted domains of science, while simultaneously abstracting the knowledge into more usable hierarchical levels of understanding. This allowed preservice teachers to transform acquired knowledge into functional knowledge for their future teaching. This ability to utilize various science concepts will increase their ability to develop more complete lessons, thus continuing to increase their PCK.

During concept map construction, representations of student knowledge gains indicated the LP was successful in increasing conceptual knowledge of initially misunderstood topics. Results also indicated that breaking knowledge up too soon into too many Primary Domains can result in fewer valid crosslinks. I believe if preservice teachers had gone beyond four Primary Domains during the initial map construction, then scores would have decreased, due to the limited number of concepts for each domain.

Limitations and Future Research

This study engaged a convenient, yet purposeful sample. Future study with a control group could lead to better understanding about preservice teachers' conceptual gains, particularly if nonthematic and vertically unaligned learning (e.g., traditional course construction of topics) were used. This study also relied upon preservice teachers' construction of open concept maps with given concept terms. A follow-up study could be developed to compare individual and group concept maps with a selected number of Primary Domains prearranged on a concept map template, compared to concept map construction, as utilized in this study, for the other test group.

I also suggestion additional studies using this particular dinosaur thematic K-12 LP for preservice teacher education. Preservice teachers could be evaluated to see how the LP experience affects their pedagogy reflected in their lesson plans. Beyond proper pedagogy, such as the inclusion of authentic science practices, lesson plans could also be examined for changes in structure, language, scientific integrity of materials and how practices in their post-LP lesson plans reflect the SCLEs they partook in during the LP.

To better understand the effectiveness of each grade-level phase, student work regarding each of the individual units of the LP could also be examined. Both formative assessments used during the LP and concepts maps of both individuals and groups could be further analyzed to achieve this goal. Concept maps after each phase could be utilized to track the conceptual progression of preservice teachers. For these investigations to be executed, researchers would need more time to implement the LP during coursework.

In addition, the LP could also be examined with K-12 students. A longitudinal study over the course of 12 years would yield information about the overall effects of the LP approach on student conceptual growth. Single studies on individual grade bands of studies would yield information about students' conceptual changes during one SCLE within the LP.

CHAPTER IV

THE IMPACT OF A LEARNING PROGRESSION ON 5E LESSON PLANNING

Introduction

Current State of Science Education Frameworks

With discoveries in science happening every day, the increases in scientific knowledge approach infinity. Just as what we know about the natural world increases, the pressure on science teachers to “teach it all” also increases. Corresponding to the logarithmic increase in scientific knowledge, school science curricula have also increased, with the result that content coverage has resulted in curricula that are “a mile wide and an inch deep.” An emphasis on content coverage leaves few opportunities for student to direct their own learning, investigate aspects of the natural world that are interesting to them, and to develop deep conceptual understandings about how the world actually works (Stuessy, 2009).

Beginning with the *National Science Education Standards* (NSES) in 1996, researchers and policy makers have challenged science educators to restructure learning goals towards enhancing students’ science literacy rather than emphasizing mastery of inert content knowledge (NRC, 1996). With the NSES, the emphasis shifted from sheer content mastery to the creation of learning environments focused on the “big ideas” of science in each of the science domain content areas (i.e., life sciences, physical science, earth and space science). States, such as Texas, followed suit with their own versions of curriculum frameworks that pared down the list of “what all students need to know and understand” to more generalized conceptions regarding how the natural world works.

The NSES recently were replaced with a new set of three-dimensional standards, emphasizing “core disciplinary ideas,” scientific and engineering practices, and “cross-cutting concepts.” A transformation of science standards into the three-dimensional framework provided opportunities to offer integrated and interdisciplinary curricula, stress performance-based practices, and make connections to the real world in learner-centered environments, while still focused on specific concepts at appropriate grade levels. National policymakers designed the *Next Generation Science Standards* (NGSS, 2013) to reflect a more conceptually based curriculum framework, integrated within and across grade bands (i.e., K-2, 3-5, 6-8 and high school), much like the strand maps of the American Association for the Advancement of Science (AAAS), which were introduced as an extension to their *Benchmarks of Science Literacy* developed in 1993.

The NGSS, which presented the core of scientific ideas progressively, allowed basic scientific ideas introduced in earlier grades to be revisited in more depth and at higher levels of abstraction in later grade level bands. While the authors of the NGSS intentionally developed a framework of standards emphasizing a progression of ideas, the authors purposely left the development of specific curriculum and instructional elements up to state and local districts, textbook developers, and science education researchers. The development of instructional materials to support a more conceptually based and integrated curriculum has been the push of many researchers in the past decade (Corcoran, Mosher, & Rogat, 2009; Plummer & Krajcik, 2010; Duschl, Maeng, & Sezen, 2011; Plummer et al., 2015). Lacking, however, has been rigorous research investigating how teachers implement NGSS-based instructional materials in their classrooms (Duschl, Maeng, & Sezen, 2011).

Student-Centered Learning Environments

Sociocognitive perspectives supporting the notion of student centered-learning environments (SCLEs) and "learning as doing" harness the suggestions of NGSS that science curricula promote scientific practice through inquiry, hands-on activities, and student investigations. SCLEs can be effective in promoting conceptual knowledge gains with proper scaffolding from the teacher (Land & Hannafin, 2000; Land, Hannafin, & Oliver, 2012; Jonassen & Easter, 2012). SCLEs centering on hands-on activities hold an additional advantage, in that researchers have found that hands-on activities also increase students' interest in science (Swarat, Ortony, & Revelle, 2012). While researchers have indicated that interest in science declines as students transition through elementary school to middle school (Kerr & Murphy, 2012), one must wonder whether the inclusion of hands-on activities in all grades would sustain students' interests in science throughout their K-12 science experience.

Learning Progressions

Suggested by the NGSS, learning progressions are new curricular frameworks designed to meet the needs of today's science learners (Corcoran, Mosher, & Rogat, 2009; Krajcik, 2011; NGSS Leads States, 2013). LPs offer a clear way to align instruction horizontally within and vertically across grade levels, thus delivering a beneficial arrangement of content to foster conceptual change in students. LPs offering inquiry experiences within and across grade levels also have the potential to solve the decline in students' interests in science, as observed by Kerr & Murphy (2012). While several researchers have attempted to develop LPs complying with the NGSS (e.g., celestial motion, Plummer & Krajcik, 2010; microevolution, Metz, 2011; formation of the solar system, Plummer et al., 2015), educators have a lack of knowledge about the use or benefits of LPs. The next stage in confirming the LP as a robust curriculum model is to perform research specifically investigating the effects of LPs on students' learning outcomes across the K-12 spectrum (Duschl, Maeng, & Sezen, 2011).

According to Duschl, Maeng, and Sezen (2011), there have been no research efforts to investigate the effects of LPs on the learning outcomes in teacher education. Assuredly, preservice teachers offer a very special type of learner for investigation. Born in the late 1990s, today's traditional college students were taught science as proposed by the NSES and other non-integrated, fact-laden and content-heavy curricula. K-12 students, in general, had few opportunities in the late 1990s to experience science as science is done, even though inquiry-based curricula had been proposed since the 1960s (Bybee et al., 2006). When our current preservice teachers were in grade school, scientific literacy was not the general goal embraced by most science teachers. "Good" teachers taught science much as it was taught to them--teacher-centered, didactic, focused on the memorization and "mastery" of factual information. As a result, the current cohorts of preservice teachers show low levels of conceptual knowledge in science (Nilsson & Loughran, 2012; Santau, Maerten-Rivera, Bovis, & Orend, 2014). This generation of preservice teachers will guide the development of the science-related workforce from K-12 learners entering the science career pipeline. As such, a study of the effects of LPs on preservice teachers' learning outcomes could have far-reaching implications of how best to prepare new teachers for teaching the new type of curriculum demanded by the NGSS framework.

As teacher preparation programs are charged with defining the up-to-date knowledge and pedagogical skills preservice teachers must possess as classroom teachers (Bybee, 2014), preparation programs for science teachers must reexamine their current practices in the light of the NGSS. LPs could hold the answer to enhancing the abilities of science educators preparing preservice teachers in science. In return, LPs could enhance preservice teachers' abilities to transform their knowledge and abilities acquired from university coursework into pedagogical content knowledge (PCK). Ideally, contemporary PCK is the type of professional knowledge possessed by teachers enabling them to design and teach interdisciplinary lessons, move away from teacher-centered models of instruction, capture the interests of students, and promote student-centered learning.

Pedagogical Content Knowledge and Preservice Teachers

Preservice teachers' growth in knowledge and experience can be summed up as PCK. PCK is "the integration or synthesis of teachers' pedagogical knowledge and their subject matter knowledge" (Cochran, 1997, p.97). Teachers with satisfactory levels of PCK understand that learning is not just the basic memorization of facts; and teaching involves much more than the basic presentation of factual information. Teachers with well-developed PCK hold a conceptual grasp on content that allows them to access and utilize their PCK to design instruction that best meets the needs of their learners.

(Wallace & Loughran, 2012). Wallace and Loughran argue that teachers' professional knowledge is developed by their extrapolation of techniques from their own training and learning.

The development of a preservice science teacher's PCK cannot be solely molded by large general science content courses (i.e., biology, geology, astronomy, chemistry). These courses, often taught in a lecture-based direct teach method, may even do more harm than good in terms of providing pedagogical examples for teaching science. Lederman, Gess-Newsome, and Latz (1994) stated that the reliance on college coursework alone is a weak model for preparing future science teachers. Similarly, Darling-Hammond (2006) wrote that theory and practice must align during teacher education courses through the modeling of "good teaching."

In previous research studies, preservice teachers who practiced reflection and investigated science content embedded in SCLEs saw growth towards their PCK (Nilsson & Loughran, 2012; Santau, Maerten-Rivera, Bovis, & Orend, 2014). Several research groups (Demirdöğen, Aydin, & Tarkin, 2015; Nilsson & Loughran, 2012; Reitano & Green, 2013) have observed a positive impact on PCK development when preservice teachers practice reflection to recognize their own gains in content knowledge and pedagogy. An important facet of reflection allows preservice teachers to ponder about how lessons were developed, organized and implemented in coursework that models good, authentic teaching.

Lesson Planning

Lesson planning is a major focus and tool for assessment in teacher education. The lesson plan provides an appropriate teacher learning product directly related to the level of a preservice learners' PCK. Transforming epistemology into practical teaching applications through pedagogically sound methods demonstrates a high-level of PCK maturation in preservice teachers. Focused efforts on science practices (e.g., argumentation) in preservice science education coursework have shown a likely transfer of this method into the pedagogy repertoire of preservice teachers (McNeill & Knight, 2013). Nilsson (2014) found preservice teachers' self-awareness about their own teaching practices may influence how preservice teachers plan their lessons.

While lesson plans are in the cache of veteran teachers, preservice teachers are just learning how to construct lessons of their own. Lesson plans can vary from direct-teach models with scripted sections to student-centered models stressing open-inquiry investigations. Science lesson plans have shifted to reflect a more authentic style. Authentic science lessons rely on the integration of authentic science practices, conceptualization of knowledge beyond a dissemination of facts, problem solving, developing scientific arguments based on evidence, and the ability to incorporate crosscutting concepts, as found in the NGSS (2013). An investigation of elementary teachers with access to real and representative science materials had more authentic plans that exemplified accurate conceptualization of science content (Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2013). Authentic preservice teacher developed lesson plans are supported through exemplar instruction that models proper pedagogy. The

BSCS 5E Instructional Model, or simply 5E lesson plan, was developed to model learning in an inquiry-based manner that is more representative of science (Bybee et al., 2006). By implementing lesson planning into assessment for preservice teachers, preservice teacher coursework can advance PCK development (Goldston, Day, Sundberg, & Dantzler, 2010).

Theoretical Framework

Activity theory provides a theoretical basis for how three basic components (i.e., Subject, Object, Mediating Artifacts) are part of a larger system (Engeström, 1987). Engeström's model for activity theory expanded upon Vygotsky's notions of learning by shifting Mediating Artifacts to Tools and Signs, and taking into consideration of other elements in the activity system environment (i.e., Rules, Community, and Division of Labor). Also, the transformation of sense and meaning into an overall outcome was established in Engeström's early work.

Jonassen (2000) transformed Engeström's established framework of activity theory to include subsystems (i.e., Production, Exchange, Distribution, Integration). These systems established small-scale interactions between different parts of the activity system. Through the foundation of doing is learning, activity theory supports the idea of multiple interactions, direct and indirect, affect the overall outcome. Subjects (e.g., students) produce Objects (e.g., assessments), and there is a resulting Outcome (e.g., conceptual learning). However, a linear path is not the track for development in activity theory. Learning is impacted by the Community (e.g., class), Division of Labor (e.g., lab groups), Tools/Signs (e.g., curriculum), and Rules (e.g., learning standards, NGSS).

I applied Jonassen's model to preservice teacher education for this study. Jonassen's Objects of activity were 5E lesson plans developed by the Subject, preservice teachers. This direct connection between Object and Subject was impacted by all the other components (i.e., Community, Division of Labor, Rules, Tools/Signs) of the activity system. The LP represents all the tangential components to preservice teachers and the concepts maps. The changes in preservice teachers' conceptual knowledge represents the overall Outcome, PCK.

Research Questions

The impact of LPs on planning has yet to be explored (Duschl, Maeng, & Sezen, 2011). The development of lessons is the method I chose to represent preservice teachers' transformation of content knowledge and pedagogical knowledge into PCK. I used science lesson plans based on a 5E design (Bybee et al., 2006) to demonstrate preservice teachers' ability to construct authentic science lessons with the integration of their content knowledge. In this study, I determined if preservice teachers' ability to develop high-quality 5E science lesson plans increased after their engagement in a four-week simulated LP. [Note: LP refers to Learning Progression, not lesson plan.]

The three research questions I crafted for this study are focused on the transformation that occurs in lesson planning by preservice teachers as a representation of their PCK development.

1. How do the levels of preservice teachers' lesson plans change after their immersion in a simulated K-12 learning progression?

2. How do preservice teachers' constructions of specific 5E lesson plan subscales (i.e., Engagement, Exploration, Explanation, Elaboration, Evaluation, additional lesson plan components) change after their engagement in a simulated K-12 learning progression?
3. How do the integrative components (i.e., authenticity, pedagogical language, materials and structure) of lesson plans change after preservice teachers engagement in a simulated K-12 learning progression?

Methods

I established this study to better understand the how LPs can affect planning as a representation of preservice teacher PCK development. Duschl, Maeng, and Sezen (2011) suggested the impact of LPs in teacher education are understudied. The particular LP I developed incorporated dinosaurs as a theme to teach both life and Earth science concepts included in a content-based science education course. This content-based course, atypical of many teacher preparation classes, incorporates content, and introduces reformed pedagogy through inquiry-based investigations. Content and pedagogy are equally emphasized and represented through model teaching and lessons.

Context

The number one science interest of students entering Kindergarten is dinosaurs (Johnson, Alexander, Spencer, Leibham, & Neitzel, 2004), yet their explicit mention in curriculum guidelines is absent (NGSS Leads States, 2013). Due to the high-interest, I established dinosaurs as the underlying theme holding the entire LP together. The LP was developed through expert-derivation for concepts. I interviewed paleontologists and science education to uncover the concepts in science that dinosaurs could be used to teach. Across five domains (i.e., Ecology, Evolution, Genetics, Geology, Organisms), 27 concepts were identified through coding for inclusion. Myself and colleagues compared identified concepts to the NGSS for identification of standards associated with dinosaurs. While none of the standards mention dinosaurs, we chose to include any standard that made reference to the 27 concepts identified by experts. Upon identification of standards, I arranged selected NGSS by grade-bands (i.e., K-2, 3-5, Middle School, High School) to determine a scope and sequence for the LP. At this time, I narrowed the LP to include four domains (i.e., Ecology, Evolution, Genetics & Organisms, Geology) based on NGSS organization. The arrangement of NGSS by grade-bands created a strand map that allowed me to identify tangential relationships between standards. With the strand map and relationships determined, I worked with a team of science education professors, graduate students and undergraduate researchers to develop four exemplar SCLEs, one for each grade-band.

Dinosaurs were used as a vehicle for delivery of content to progress preservice teachers from early elementary (i.e., first-grade SCLE) to a high school biology SCLE. During my interview with Thomas Holtz, he suggested his introductory geology course is popular based upon the inclusion of dinosaurs into the course title. Scott Sampson of *Dinosaur Train*, another one of my interviews, said that basically any life science topic and a majority of Earth science concepts can be taught using dinosaurs. This statement aligned with all other interviews. The dinosaur LP focuses on Earth and life sciences.

Dinosaurs were a perfect thematic vehicle to model for preservice teachers that concepts to be taught are found in curricular guides like NGSS, but the subject can be a topic of high interest (e.g., dinosaurs, space exploration) to their future students.

Participants

I collected data from a science content course designed for preservice teachers in the form of 5E lesson plans. Two lesson plans were collected from every participant. Any student who did not provide consent, failed to develop two unique 5E plans with different NGSS selected, or was absent for portions of the dinosaur LP intervention were excluded from the study. The dinosaur LP was implement in two sections of a content-based science education course focusing on life and Earth science that I taught. Participants for the study were recruited from these courses at a large research university in the southern United States.

A sample size of 70 preservice teachers (n=70) are included in the analysis. The preservice teachers are all Early Childhood through sixth grade (EC-6) or fourth grade through eighth grade certifications (4-8). The EC-6 certification students are seeking a generalist certification, while 4-8 certifications will be focused in either math/science (M/S) or English language arts/social studies (ELA/SS). While no preservice teachers will be initially certified for high school, the inclusion of the biology SCLE is relevant for preservice teachers to understand the progression of learning expectations occurring from elementary to middle to high school.

Design

I used an explanatory mixed method design for this study (Creswell & Plano Clark, 2011). Although multiple data collections occurred throughout the study, I chose to analyze only the pre- and post-intervention lesson plan data sets. Lesson plans were both quantitatively and qualitatively analyzed to explore changes to overall plan and subscale construction. I utilized quantitative analyses to identify how pedagogy is impacted by preservice teachers undergoing a four-week intervention with a LP. Pre- and post-intervention lesson plans were analyzed to identify changes in pedagogy for the overall 5E lesson plan and individual 5E components. I explored the content knowledge component for analysis during explanatory analysis of 5E plans.

Procedures

Instrumentation. I used basic 5E lesson plan outline was utilized as a template for the preservice teachers participating in this study (Bybee et al., 2006). I used the 5E Inquiry Lesson Plan Version 2 Rubric (5E ILPv2) developed by Goldston, Dantzler, Day and Webb (2013) for scoring the lesson plans created by the preservice teachers. I provided preservice teachers with the scoring rubric as a guideline for the development of their pre- and post-lesson plans. No sample lesson plans were provided to preservice teachers.

Data collection. Prior to enactment of the LP, I directed preservice teachers to develop their first-ever 5E science lesson plan. Students were instructed to reference the provided 5E scoring rubric (5E ILPv2) for expectations and structure of each subscale of the overall 5E plan (Bybee et al., 2006; Goldston, Dantzler, Day, & Webb, 2013). I provided the standards from the NGSS for preservice teachers to select for the basis of their lessons (NGSS Leads States, 2013). The selected standards of the NGSS provided to participants coordinated with the learning objectives that the preservice teachers experienced as part of the simulated LP on dinosaurs.

Preservice teachers experienced a four-week LP on life and Earth science learning objectives that revolved around the central theme of dinosaurs. Each week, instruction focused on a different grade of a grade band and included a SCLE that was developed around the 5E lesson plan model. I began each SCLE with an Engagement activity, followed by an inquiry-based Exploration phase and Explanation of concepts by preservice teachers and myself. Elaboration of the initial inquiry into another discipline or semi-related topic followed these phases and conclude with an Evaluation. I collected formative assessments associated with different learning phases of the coordinating SCLEs during all different phases of the LP. However, analyses of these evaluations are beyond the scope of this study. At the end of each class meeting, preservice teachers were given time to reflect about how the SCLE was organized to include authentic science practices, materials and inquiry-based pedagogy. The class met once a week for three hours at a time. SCLEs of the four-week intervention (i.e., first-grade SCLE, third-grade SCLE, middle school SCLE, high school SCLE) covered one class meeting per SCLE.

Preservice teachers received pre-test (i.e., the first 5E lesson plan attempt) scores back during the four-week LP. Upon completion of the four-week simulation of the LP, preservice teachers crafted another 5E lesson plan about a different Core Idea(s) from the list of selected NGSS Core Ideas provided. Preservice teachers had ten days after the completion of the four-week integrated K-12 life and Earth LP on dinosaurs to submit their final lesson plans.

The learning progression as an intervention. The LP I developed on dinosaurs focused on four specific exemplar 5E lessons constructed to represent the theory behind SCLEs (Bybee et al., 2006; Land & Hannafin, 2000). The four lessons represented the four different grade bands as defined by the NGSS (NGSS Leads States, 2013). The four bands of concentration included K-2, 3-5, Middle School and High School. During the development and sequencing of the LP, multiple core ideas in elementary grades were identified for inclusion. However, I decided for simplification of data collection only one grade per grade band would be included in the LP intervention. Intermediate levels of knowledge sophistication are included in the actual LP, but discussion of those levels is beyond the analysis of this study (Corcoran, Mosher, & Rogat, 2009; Plummer & Krajcik, 2010; Duschl, Maeng, & Sezen, 2011; Plummer et al., 2015).

K-2 student-centered learning environment. The early elementary SCLE concentrated on first-grade core ideas (i.e., 1-LS1-1, 1-LS1-2, 1-LS3-1; NGSS Leads States, 2013). Preservice teachers categorized traits and behaviors of dinosaurs that helped adult and baby dinosaurs survive. They developed an argument based on artifacts that baby dinosaurs are similar, but not exactly like, their parents. As a summative assessment, preservice teachers, simulating the role of a first grade student, solved an everyday problem by using traits found in dinosaurs.

I began the SCLE with a simple Engagement of draw-a-dinosaur to establish prior knowledge of preservice teachers. Later in the Engagement, I showed *Dinosaur Train*, a PBS program under the direction of paleontologist Scott Sampson, to incorporate age appropriate and scientifically factual media into the lesson (i.e., Core Idea 1-LS1-2). It is worth noting that Sampson was one of the paleontologists I interviewed during the development of the LP. The SCLE progressed with an Exploration that included an examination of traits found in dinosaur models and hypothesizing the ages of different *Triceratops* based upon skulls.

An Explanation, by preservice teachers and myself, followed with reference to different dinosaur traits and how these traits aided in survival. Preservice teacher Explanations were based on findings from the Exploration inquiry. The Elaboration included two activities. First, preservice teachers worked on correlating traits found in dinosaurs to modern animals. Second, a follow-up and extension on offspring and parents was completed using a different *Dinosaur Train* video that explored how a crest on *Corythosaurus* changed during development, a reference to the sorting activity in the Exploration. Finally, Preservice teachers attempted to identify a problem they experience every day that could be solved using a trait or combination of traits found in nature, preferably dinosaurs, as their summative Evaluation.

3-5 student-centered learning environment. While the early elementary SCLE implemented whole-class and small group instruction, representative of a first-grade classroom, I designed the later elementary SCLE to include stations for inquiry. Stations have been very popular among classrooms these preservice teachers will intern in during senior methods. My rationale for constructing this SCLE to include stations that support inquiry was imperative for their future growth. It was crucial for these preservice teachers to experience a more scientifically sound station-based SCLE. The later elementary grades SCLE focused on third-grade core ideas (i.e., 3-LS1-1, 3-LS2-1, 3-LS3-1, 3-LS3-2, 3-LS4-2, 3-LS4-3, 3-LS4-4; NGSS Leads States, 2013). The learning objectives for this third-grade lesson required preservice teachers to interpret data about the fossil record to make claims about past organisms, develop models and arguments about what all dinosaurs have in common, suggest how behaviors aid in survival, use evidence to develop arguments about how dinosaurs' genetic differences aided in survival, determine how the environment determines traits of organisms and make a claim about what happens to dinosaurs after environmental changes occur.

I introduced preservice teachers to the SCLE by having a discussion about basic topics on deep time. As suggested by Thomas Holtz, a deep time activity was utilized for the remainder of Engagement. I instructed to students to build a *Dinosaur Timeline* using a strip of adding machine tape, cutouts of various organisms listed on the timeline and directives about where to place certain events (AMNH, 2005). By mimicking rock layers and stratification of fossils, preservice teachers were exposed to facts like grass evolving after the age of dinosaurs, *Tyrannosaurus rex* being closer in time to us than *Stegosaurus*, and the coexistence of mammals and dinosaurs subsisted for 145 million years. This activity ties into one of the stations in the Exploration and into later parts of the 5E lesson cycle. Students then transitioned to the station-based Exploration that incorporated five stations with 12 minute rotations. Preservice teachers worked both as individuals and small groups at the stations completing a packet designed as a formative assessment for Exploration. The stations included (1) sorting dinosaur traits of like organisms, (2) predator and prey relationships found in pack hunting and herding for survival, (3) dinosaur life cycles, (4) traits impact on behaviors of dinosaurs (e.g., parenting, hunting, protection), and (5) a fossil layer puzzle reconstruction. Vertically aligning traits and behaviors from the first-grade lesson to more in-depth analysis and incorporation of geologic principles defined this inquiry. The media I incorporated into the Exploration included scientifically authentic and accurate sources. Images were taken from paleoart found in *Dinosaurs: The Most Complete, Up-to-Date Encyclopedia for Dinosaur Lovers of All Ages* (Holtz, 2007). Videos integrated into the stations included *BBC Walking with Dinosaurs* (Haines & James, 1999), *BBC Planet Dinosaur* (Paterson, 2011), and *Discovery Kids: Dinosaurs* (2017).

I began the Explanation with students sharing their findings from the Exploration. I provided corrections for any scientific misconceptions that may have been acquired. A short PowerPoint of concepts in a direct-teach method with more videos from the sources incorporated to provoke whole-class discussions concluded the Explanation. Elaboration focused on students applying knowledge of genetic traits, life cycles, heterotrophy, deep time, evolution, ecology and principles of survival within particular habitats. I included two whole-class activities with 15 minutes provided for each during this phase. Preservice teachers incorporated previously covered topics with ecology concepts. For part one of the Elaboration, I asked preservice teachers to hypothesize were dinosaurs could survive today, compare extinct life to extant species, use the predeveloped *Dinosaur Timeline* to craft scientific arguments why certain traits were prevalent in dinosaur habitats but not today, and determine where fossils could potentially be found when looking at a map of the world (e.g., laying the ground work for plate tectonics). Part two focused on *Therozinosaurus*, a relatively odd species of dinosaur, that required preservice teachers to draw conclusions about its behaviors and diet based on morphology of visible traits. Finally, the Evaluation had preservice teachers make a claim about what would happen to dinosaurs given different ecological scenarios including weather issues, food scarcity, and the emergence of different types of plants to a habitat.

Middle school student-centered learning environment. Middle School NGSS are not based upon specific grade levels, thus standards explored in the Middle School SCLE may not occur in the same grade level depending on the adopting state, district or campus guidelines. I purposively integrated life and Earth science topics outlined for middle grades in this SCLE. Earth science standards (MS-ESS1-4, MS-ESS2-2, MS-ESS2-3; NGSS Leads Sates, 2013) focused on analyzing and interpreting fossil distribution, plate tectonics, geologic time scale via rock strata, and geological processes change the Earth's surface. Life science in the Exploration phase had preservice teachers analyzing fossil record patterns to interpret existence, diversity, extinction and evolution (MS-LS4-1), constructing scientific arguments for morphological homologous, analogous and vestigial structures to infer evolutionary relationships (MS-LS4-2; NGSS Leads States, 2013). Preservice teachers' ability to make determinations based on resource availability impact on organisms and ecosystem (MS-LS2-1) and developing a scientific argument rooted in evidence about how geological and biological components affect populations of an ecosystem (MS-LS2-4) were the emphases of Elaboration.

During Engagement, preservice teachers created a model of Pangea based on fossil evidence (AMNH, 2007). I had preservice working together in small groups during Exploration to uncover fossils in their designated sites during a Dino Dig inquiry. Dig sites were organized into plastic bins with multiple pieces of dinosaur "fossils" found in one of three different rock layers (i.e., Triassic, Jurassic, Cretaceous). Preservice teachers uncovered the fossils in their dig site and identified the organisms based on morphological traits and geologic stratification using a set of identification cards. Once identification was completed for small groups, three coordinating dig sites (e.g., Site 1A, Site 2A, Site 3A) collaborated with one another to determine if other fossils were found in respective rock strata. Due to the size of the classes, I utilized multiple locations (e.g., Location A, Location B, Location C), thus forming three larger Locations that each incorporated three different Sites at each Location. Each location included 12 species for identification and was accompanied by a student-developed map for uncovering the fossils. I also requested preservice teachers identify the geological layers coordinating with each fossil discovery. An important not, I questioned each course section prior to the Dino Dig and neither section could name the three geologic time periods of the Mesozoic era, let alone the order of occurrence.

I followed the Dino Dig inquiry with the Explanation phase. Preservice teachers shared findings of their constructed a collaborative "Class Dig Map" and identified species of dinosaurs from the Exploration. I then facilitated discussions about why certain species were identified and the order of geologic time periods. A short PowerPoint was used to explain some basic principles of geologic time, “Invalid Hypotheses,” and “Current Arguments” for why dinosaurs went extinct and a discussion of how sudden geologic events could create a mass extinction (Smith, 2005). I concluded the Explanation with a TED Talk, *Hunting for Dinosaurs Showed Me Our Place in the Universe*, by paleontologist Kenneth Lacovara, which set up the eventual Evaluation for the SCLE (Lacovara, 2016). Elaboration included three main areas. First, students constructed arguments for what types of environments dinosaur fossils found in the Dino Dig based on genetic traits and geologic records. Second, preservice teachers determined how changes in abiotic and biotic factors affected extinction and evolution of particular species. Third, preservice teachers used evidence from ecosystem nce to develop scientific arguments about where dinosaurs identified during Dino Dig could survive and why. I assessed both conceptual knowledge of Earth and life sciences during Evaluation. Preservice teachers, in groups, constructed a dichotomous key based upon evolutionary relationships (i.e., time period, anatomical structures) of dinosaurs uncovered during the Dino Dig. A geological survey was also explored as a class under my direction. I used geologic maps from Lacovara’s TED Talk to ask questions about fossil distribution across North America in reference to geologic time and evolution.

High school student-centered learning environment. The SCLE developed for high school NGSS (HS-LS2-6, HS-LS2-8, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5, HS-ESS-7) was developed around a board game that would incorporate the main life science standards (i.e., evolution, genetics, ecology) of the LP. I referenced

Earth science concepts for integration of topics for conceptual development. I began the Engagement for the high school SCLE with a student-led discussion of key concepts that would be needed for the Exploration. Concepts included traits, morphologies, ecosystem, behaviors, resources, extinction, evolution, habitat, mutations, genetics, geologic time, diversity, competition, and other topics covered in previous SCLEs. During Exploration, I focused on the board game *Evolution* by North Star Games. I developed a specialized deck of cards that only used dinosaurs for images on cards was created for this specific SCLE. Each group of preservice teachers would play the game with three or four group members and develop a "living" ecosystem that required them to adapt via natural selection over time (evolve) or go extinct. Each group included one "game expert" that had previously played the game with myself and other "game experts" prior to class. This was an effort to limit the learning curve of gameplay.

I followed the game with a group discussion about how different scenarios, ecosystems and games developed during Exploration. The Explanation included their discussion points based on evidence from gameplay followed by my clarifications of any misconceptions. Evidence from gameplay allowed preservice teachers to construct scientific arguments about how to "best" survive in the age of dinosaurs (HS-LS4-4, HS-LS4-3, HS-LS4-5, HS-LS2-8). Elaboration incorporated geologic events during the Mesozoic era. Preservice teachers, as groups, hypothesized what would have happened to their species in their developed ecosystems during gameplay if specific geologic or cosmic events would have occurred. Evaluation required individuals to provide evidence from their gameplay that the process of evolution primarily results from four factors (HS-LS4-2). Also, preservice teachers were required to explain how homeostasis is maintained in ecosystems during stable conditions, but changing conditions (i.e., limiting food for herbivores, introducing new predators) may result in a new ecosystem (HS-LS-6), based upon evidence from their gameplay.

Results

Lesson plans were scored by myself and a colleague to determine interrater reliability using the 5E ILPv2 rubric (Goldston, Dantzler, Day, & Webb, 2013). A Cohen's Kappa of 0.861 was established by raters for a high level of satisfactory reliability (Fraenkel, Wallen, & Hyun, 2012). Preservice teacher 5E lesson plans were scored using ratings from the 5E ILPv2 rubric. Scoring ranged from an Unacceptable, zero value, to an Excellent with a value of four. An Unacceptable was given when items for a criterion were not present or inappropriate. A Poor rating was given if any element would need to be completed reworked but was present in some form. Acceptable scoring of Average, Good, and Excellent were given to plans that contained components that were usable if the plan was given to another teacher. Average ratings still required modifications with about half the elements being "present, complete, appropriate and accurate" (Goldston, Dantzler, Day, & Webb, 2013). Good components included a majority of complete elements with "rich details" and little modification needed. Excellent plans were usable as written and required all elements of the component to be included and accurate.

The 5E ILPv2 rubric utilizes 7 subscales with varying elements included in each category. A total of 28 components make up the entire scoring rubric. Preparing The Lesson (PTL) includes 3 components that must all be completed prior to planning the lesson. Phase 1 includes Engagement and Exploration with each subscale containing four components. Phase 2 includes the Explanation, which incorporates six different components, the most of any one subscale. Phase 3 of the 5E lesson plan includes the Elaboration and Evaluation. Elaboration is rated by three components, while Evaluation features four components. Additional Lesson Plan Components (ALPC) includes other relevant portions of a complete 5E lesson plan like time requirements, safety issues, accommodations and references for a total of four scored components. Table 1 includes pre- and post-intervention of class means and standard deviations for the overall lesson plan and subscales.

The overall lesson plan score and subscales of PTL, Engagement, Exploration, Explanation, Elaboration, Evaluation and ALPC were analyzed using paired-samples t-tests. With the ability to pair individual's pre-intervention lesson plans to post-intervention lesson plans, this quantitative analysis was appropriate. A follow up explanatory analysis of why significant changes occurred was completed by analyzing the text of the lesson plans, identifying trends and supporting with low-inference quotes from selected preservice teacher developed 5E lesson plans.

Quantitative Analysis of 5E Lesson Plans

Variables were computed for each subscale (i.e., PTL, Engagement, Exploration, Explanation, Elaboration, Evaluation, ALPC) of the 5E lesson plans (n=70). Computed variables averaged the scores of each subscale and overall score for each individuals pre- and post-intervention 5E lesson plan. This provided seven categories to compare via paired-samples t-tests. Each category would have a minimum score of 0 and a maximum of 4 to correlate with the terminology and operational definitions found in the 5E ILPv2 rubric (Goldston, Dantzler, Webb, & Day, 2013).

Preservice teacher scores on pre-intervention 5E lesson plans were very low, as you would expect on their first ever 5E science lesson plan. However, there were some usable lesson plans developed prior to intervention. Preservice teachers had a decent grasp of choosing appropriate national and coordinating state standards, writing effective lesson objectives, and including a list of materials needed. All other subscales had a class mean that would deem the collective average of pre-intervention 5E lesson plans to be unusable. Post-intervention scores saw large increases in means with standard deviations remaining relatively constant to pre-intervention scores. Unlike pre-intervention plans, there were no post-intervention plans to score a zero for any subscale and all subscales other than Explain had at least one individual plan score a perfect score. Although it may appear that the maximum score was achieved the highest overall score of any on individual plan was a 3.5, thus no one plan had a perfect score. Rather multiple students excelled in different portions of lesson planning.

Table 13 organizes class means and standard deviations for the overall 5E lesson plan and subscales. Prior to LP intervention with exemplar 5E-based SCLEs,

Table 13

Class Level (n=70) Means and Standard Deviations for Overall 5E Lesson Plan and Subscales

	Pre-intervention class scores				Post-intervention class scores			
Subscale	Mean	SD	Minimum	Max	Mean	SD	Minimum	Max
PTL [a]	2.24	.74	0.67	3.67	3.18	.49	2.00	4.00
Engage	1.45	.62	0	3.25	2.96	.62	1.25	4.00
Explore	1.19	.68	0	2.50	2.79	.69	1.25	4.00
Explain	1.17	.65	0	2.67	2.55	.60	1.00	3.67
Elaborate	1.09	.81	0	3.00	2.53	.89	0.67	4.00
Evaluate	0.89	.64	0	2.75	2.56	.78	0.75	4.00
ALPC [b]	1.31	.53	0	2.75	2.94	.60	1.00	4.00
Overall	1.30	.42	0.43	2.50	2.77	.49	1.57	3.50

[a] PTL refers to Preparing The Lesson
[b] ALPC refers to Additional Lesson Plan Components

Explanation, Elaboration and Evaluation were the three lowest scoring subscales. These three subscales remained the lowest class level means after intervention. Of the five main phases of the 5E lesson cycle, Engagement and Exploration maintained the trend of highest class level means on post-intervention lesson plans. One important note on the individual level, no lesson plans had an overall lower score on post-intervention developed plans.

Table 14

Paired t-tests Analyses of Overall 5E Lesson Plan and Each Subscale

Paired sample	Mean difference	Std. deviation	*t*	*df*	Sig (2-tailed)
Pre-PTL - Post-PTL[a]	0.9***	0.8	10.243	69	.000
Pre-Engage - Post-Engage	1.5***	0.7	17.190	69	.000
Pre-Explore - Post-Explore	1.6***	0.9	14.987	69	.000
Pre-Explain - Post-Explain	1.4***	0.8	14.810	69	.000
Pre-Elaborate - Post-Elaborate	1.4***	1.2	10.258	69	.000
Pre-Evaluate - Post-Evaluate	1.7***	0.8	17.179	69	.000
Pre-ALPC - Post-ALPC[b]	1.6***	0.6	21.450	69	.000
Pre-Overall - Post-Overall	1.5***	0.5	24.560	69	.000

[a] PTL is abbreviated for the subscale Preparing The Lesson and involves components including Standards, Lesson Objectives and Materials.

[b] ALPC is abbreviated for the subscale Additional Lesson Plan Components and involves components including Safety, Time, Accommodations and Bibliography.

Table 14 represents the findings of the paired-samples t-test analysis for pre- and post-LP intervention preservice teacher developed 5E lesson plans. Significant improvements in lesson plans were found for every scoring subscale, as well as the overall plan. All subscales and overall scores had an effect size over 1, confirming a large shift in planning ideology occurred following the LP. The PTL subscale had a mean difference of 0.9 from pre- to post-intervention developed lessons (p<.001, t=10.24). Engage (p<.001, t=17.19), Explore (p<.001, t=14.99), Explain (p<.001, t=14.81), Elaborate (p<.001, t=10.26), Evaluate (p<.001, t=17.18), and ALPC (p<.001, t=21.45) subscales all had average scores increase by 1.4 or more. Overall lesson plan scores were significantly better (p<.001, t=24.56) after the intervention with scores increasing 1 to 2 criterion scoring levels.

A Further Explanation through Qualitative Descriptive Analysis

Referring back to Table 1, it is easy to see that lesson plan components were trending upward after the LP. To better understand if preservice teachers' post-intervention 5E lesson plans include elements from the LP, an explanatory descriptive qualitative analysis was conducted on individual plans to develop themes present in post-intervention plans that may have accounted for significant gains for subscales, as well as the overall plan.

Overall, preservice teacher post-intervention plans included more student-centered manipulatives that mimicked the pedagogy implemented in the four exemplar SCLEs. Language shifted from "I will" or "The teacher will" to "Students will," thus reflecting a more reformed and inquiry-based pedagogy. Phrases including "Please do not touch the materials on your table until asked to do so," were prevalent in pre-intervention plans, while plans encouraged student involvement after intervention with the dinosaur LP. Explorations were more "cookbook" prior to their experience with the LP. While step-by-step instructions still occupied the Exploration sections of 5E plans post-intervention, language used reflected learning objectives and verbs in Core Ideas more closely. Authentic science practices and crosscutting concepts were infused more in Exploration. Explanations became more robust overall and relied less on PowerPoint presentations. However, when PowerPoint presentations were included, a justification was rationalized by more plans post-intervention. Elaboration on pre-intervention plans typically rehashed the exploration and did not progress learning to new areas. After the LP, Elaboration plans included new concepts and content that differed for previous phases of the 5E plan. Many of the plans also attempted to integrate various Core Ideas, as compared to primarily one Core Idea on pre-intervention lesson plans. Evaluations were better aligned to learning objectives and included more appropriate summative evaluations. Evaluation sections were also measurable with most containing a rubric or scoring guide that was almost completely omitted on pre-intervention plans.

There were also some other interesting trends of note that reflected the rigor and implementation of the LP. Topics for lesson plans diverged from the word-for-word, explicit language found in Core Ideas of NGSS. Lessons incorporated more student interests. One middle school 5E plan was based around a popular video game that deals with an outbreak that happens when a fungus mutates to infect humans at an alarming rate. Variation increased in post-intervention 5E plans and reflected the SCLEs, as no SCLE included a complete repetitive plan for all 5E phases. Finally, science accuracy and proper conceptualization of content emerged in post-intervention plans. Science was represented more accurately and manipulatives were from more reliable sources. For example, videos utilized in plans reflected the quality of videos incorporated into the LP. A typical video prior to intervention was a sing-a-long about a particular science concept, while post-intervention had more scientific videos often from a reputable source (i.e., BBC, Discovery, PBS, Crash Course).

Discussion

Students were assessed formatively throughout each 5E-based SCLE and summatively during each Evaluation phase. While LPs generally track development of learning over time, this study focused on the impact of preservice teachers experiencing a LP grounded in 5E-based SCLEs. Novice, Intermediate and Expert levels of knowledge exist for each of the 4 exemplar SCLEs, just as any well-developed LP should include. As a measure for assessing PCK development, lesson planning, and the affect LPs have on this skill were the focus for analysis.

Duschl, Maeng, and Sezen (2011) recommended that how LPs are used in actual planning and teaching are understudied. Corcoran, Mosher, and Rogat (2009) defined LPs as a method for aligning curricular structures to cultivate an understanding of overarching ideas in science. The dinosaur LP developed for this intervention worked to achieve this goal with respect to how preservice teachers were better able to transform

PCK into preparing lessons., while building foundational knowledge in the NGSS Core Ideas embedded in the LP. No one journey was cognitively the same for any single preservice teacher during the LP intervention. Krajcik (2011) explained that multiple pathways to higher levels of conceptual understanding and knowledge building are experienced during LPs. This variety be seen in the 5E lesson plans (i.e., topics chosen, methods used, resources, grade level).

LPs in science teacher education can positively impact preservice teacher lesson plan development. Utilizing inquiry pedagogy, 5E-modeled lessons, SCLEs, and infusing crosscutting concepts into science education coursework that is vertically aligned and continually building upon foundational knowledge acquired in previous lessons has a significant positive effect on this essential skill. Growth was seen across all subscales and in overall plans. The ability for preservice teachers to transform their experiences in the dinosaur LP and craft their own life and/or Earth science lessons impacted the early PCK development of these preservice teachers. The quality of the PTL subscale improved from “average” (M= 2.24) to “good” (M=3.18) by Goldston, Dantzler, Webb, and Day’s (2013) operational definitions. All other components (i.e. Engagement, Exploration, Explanation, Elaboration, Evaluation, ALPC) of lesson planning improved to what I would deem to be “above average” or “good.” The overall lesson plan class mean suggests that improvements are still possible and implementation of similar strategies in other science education coursework may improve lesson planning further. All of the remaining subscales improved on average by more than 1.4 points out of a 4.0 scale. The shift in ideology from teacher-directed to student-centered lessons was a large contributing factor. The increase in lesson plan authenticity to science and the incorporation of science skills were also causative influences on the improvement seen in lesson plans. Student-centered instruction, authentic science practices and accurate conceptual science content were critical components that were stressed in the pedagogy implored throughout the LP. Integration of multiple topics was at the heart of the LP design and many post-intervention 5E plans echoed this effort.

Future studies on LPs, lesson planning and PCK development need to be carried out to further investigate LPs as an intervention in science teacher education. There is a need to investigate the intermediate learning steps that occur during the LP intervention with preservice teachers. This was also the first cycle of LP implementation into science education coursework, so replicating this study with more control could reaffirm the conclusions of this study. A panel discussion with participants could uncover elements of the LP that had the most self-perceived impact on their PCK development with respect to pedagogy in planning. Other LPs need to be developed or modified for science teacher education that include astronomy, physical, and chemical sciences. While this study explored Earth and life sciences concepts and the development of lesson plans in the disciplines embedded throughout the LP, other geology and biology-based LPs should be developed to cover other essential concepts.

It is also worth noting that I was the only instructor for the course during the semester of intervention, but recruitment and enrollment of participants was done by a third party. Participants were names were coded and kept confidential. This ensured anonymity of students and allowed the class to function without any prejudice towards any students. Limitations of the study include the purposive sampling and lack of a control group. Reasons for the lack of control are two-fold. First, the lack of a control group allows all preservice teachers to receive the same instruction for the course; second, the lack of a control group protects against having too few participants for quantitative analysis. To understand more about the impact of the LP on preservice teachers' ability to apply their PCK to transform hands-on experience to develop high-quality lesson plans, I would recommend replication studies using control and test groups in differing semesters, at different universities or with a coordinating instructor of a different section of the course.

CHAPTER V

SUMMARY

Conclusions

In this dissertation, I report on the results of three independent, yet related, research investigations relating to the development and experimental use of an optimal learning environment designed specifically to enhance the development of pedagogical content knowledge (PCK) in preservice teachers. I implemented the learning environment in an innovative content-based science education course focused on Earth and life sciences. Within the structure of the course, preservice teachers experienced their learning of science content with reformed models of instruction to combat the "teaching as they were taught" models implemented so frequently in contemporary K-12 classrooms. I taught preservice teachers Earth and life sciences concepts through dinosaurs using science practices (i.e., scientific argumentation, analyzing data, making predictions) and science pedagogical methods (i.e., inquiry-based learning). The innovative structure of the content-based course provided an ideal context for investigating models of reformed instruction alternative to the predominant, more traditional, method of teacher-directed lecture.

As the instructor of the content-based science education course, I aimed to provide an optimal science learning experience for preservice teachers that would be much like the reformed science learning environments K-12 science teachers are currently expected to implement in their own classrooms. My instructional intent was to develop and implement an example of an alternative model for science teaching and learning that complied with reformed practices recommended by policymakers in science education. My research intent was to use the alternative model as an intervention to substantiate the learning outcomes associated with preservice teachers' engagement in the model. Specifically, I desired to provide evidence that the optimal learning environment had advanced two essential components of PCK: preservice teachers' (1) conceptual understanding about science, and (2) understanding about how to teach science.

At the time of the research, students currently enrolled in the content-based science education course were all preservice teachers. This provided a convenient, yet purposive, sample of participants for implementing research studies supporting a claim or claims about the effectiveness of an alternative, reformed teaching and learning model designed to advance preservice teachers' knowledge about science content. At the same time, the study additionally focused on advancing preservice teachers' knowledge about how to teach science.

Learning Progressions

My examination of potential curriculum frameworks for the design of the optimal learning environment led me to consider the learning progression (LP), an innovative curriculum framework currently being developed by several science education researchers. Briefly, Simon's description of the LP, offered in a review authored by Duschl, Maeng, and Sezen (2011), appeared most promising:

> Simon (1995), writing about mathematics learning, suggests that LPs include 'the learning goal, the learning activities, and the thinking and learning which students might engage' (p. 133). … [representing] a shift in emphasis from partitioned teaching of independent units/modules of instruction which focus on what we know (e.g., facts and skills) to coordinated sequential teaching that focuses on developing scientific and mathematic knowledge with accompanying cognitive and metacognitive practices. The recommendation is that science/math learning be connected through longer sequences of instruction (e.g., immersion units, LPs, LTs) that function across grades/years and horizontally within a given school year. The rationale is to facilitate the learning of core knowledge and practices that are critical for development of science/maths knowledge and reasoning. … The focus is for LPs to be built around the most generative and core ideas/practices that are central to the discipline and support students' learning. (p. 124)

While numerous LPs had been designed as "hypothetical learning progressions," Duschl, Maeng, and Sezen also reported that the ways LPs were used in teaching and planning was understudied. In addition, these authors also reported that LP research had occurred only in K-12 settings. Research questions had not been asked regarding the effectiveness of LPs in preservice teacher education. My instructional and research interests were not only timely; they had the potential to answer questions yet unasked about the use of LPs with preservice teachers. To follow through with my plan to design, implement, and research the unique outcomes associated with LPs in preservice teacher education, I would have to focus on the unique needs of preservice teacher preparation: to advance preservice teachers' science knowledge while also enhancing their knowledge about science pedagogy. Furthermore, to be most effective, I reasoned that the LP had to simulate K-12 learning as specified by LP developers so that my students could learn as they would teach and thus ease their transfer of preservice preparation experiences into their own classrooms when they became teachers.

Development of a Dinosaur Learning Progression

All LPs have some thematic reference for the entirety of the learning process. These themes situate learning and encourage the use of interesting, interdisciplinary contexts. I chose Dinosaurs, one of the most interesting facets of science for children entering school (Alexander, Johnson, Leibham, & Kelley, 2008; Johnson, Alexander, Spencer, Leibham, & Neitzel, 2004), as my choice for thematic reference, or topic. My earlier investigations centering on the inclusion of dinosaurs in K-12 curriculum standards revealed that dinosaurs had a history of exclusion in standards documents, reaching way back to the early 20th Century. Although this finding was not unexpected, I deemed the exclusion a missed opportunity, due to learners' high interests in them. With high student interest (as well as my own) interest in dinosaurs, I set out to develop a LP on dinosaurs to offer the students in my course. As the processes for LP development were and are still up for debate, I believed that offering and testing a new method for LP development would be a contribution in science education that could be replicated for other thematic interests.

Identifying Generative, Core Ideas Central to the Discipline

To identify “the most generative and core ideas/practices central to the discipline” (Duschl, Maeng, & Sezen, p. 124), I used a grounded theory approach and designed a qualitative research investigation advancing Wolcott’s Description-Analysis-Interpretation (1994) model. I removed any bias of myself or various members of my LP development team by using experts (i.e., science education professors, paleontologists) as my sources for identifying the core ideas/practices central to an LP on dinosaurs. The concepts I incorporated into the LP came from both content and pedagogy experts, which allowed for multiple perspectives in regard to the creation of a well-rounded and robust LP. The decision to use outside experts to build a consensus regarding content and pedagogy opposed a popular assumption about developing curriculum. No single person, or even an internal team of science educators, could develop a totally unbiased LP. To increase the content validity and the viability of any LP, but particularly one developed for learners at the university level, I chose experts with teaching experiences similar to my own.

My analysis of interviews of experts led to the consensus of experts I sought. To confirm the consensus, I referenced the *Next Generation Science Standards* (NGSS) as my choice of an expert document to triangulate the results of my analysis. The 27 concepts identified for the Dinosaur LP aligned with topics in Earth and life sciences across all grade bands (i.e., K-2, 3-5, Middle School, High School) in the NGSS. Already formatted as standards for learning science, I used the standards from the NGSS to constructed a strand map visualizing vertical alignment and relationships to NGSS

Core Ideas. These research activities formed the foundation for the development of lessons aligned with the grade band levels of understanding, which led to the finalization of the LP to be used with the preservice teachers in my course.

Observing Pedagogical Content Knowledge Gains

Pedagogical methods courses focus on the enhancement of preservice teachers' pedagogical knowledge (Ball, 2000). In contrast, typical science courses focus on content mastery and provide a poor context for advancing preservice teachers' pedagogical knowledge (Lederman, Gess-Newsome, & Latz, 1994). Low levels of science teacher PCK is a limiting factor with LPs (Krajcik, 2011). By using my dinosaur LP, I aimed to address both pedagogy and content within one content-based science education course. I was able to measure how conceptual changes of preservice teachers by analyzing the concepts maps of individuals and groups before and after the LP intervention. Preservice teachers 5E lesson plans were also collected prior to and following the LP for analysis. Analyses of concept maps and lesson plans resulted in significant gains for preservice teachers conceptual understanding and pedagogical planning. Overall, PCK of preservice teachers increased after the dinosaur LP intervention.

Conceptual change (concept map comparisons). A comparison of pre-post LP concept maps revealed that preservice teachers showed significant gains in their ability to use concepts, make meaningful connections between concepts and interrelate concepts across science domains (e.g., connect Evolution to Geology). This significant positive shift in conceptual knowledge occurred both in individual and group maps.

Through distributed cognition processes supporting group concept map constructions, preservice teacher groups had significantly higher conceptual gains than the mean score of individuals for any one group. After experiencing a LP on dinosaurs, preservice teachers' conceptual understanding of the related 27 concepts significantly increased.

Pedagogical change (lesson plan comparisons). Lesson plans of preservice teachers were impacted positively after the LP intervention. A significant positive change was found in overall plans and all 5E components (i.e., Prior to the lesson, Engagement, Exploration, Explanation, Elaboration, Evaluation, Additional Lesson Plan Components). Prior to the LP intervention, lesson plans of preservice teachers were poorly constructed and were deemed "unusable" on average. After the intervention, lesson plans were more like the ones they experienced during the LP. Authentic science materials, quality sources, science practices, crosscutting concepts and student-centered pedagogical methods were all incorporated into the post-intervention developed lesson plans. Post-intervention developed plans had to be focused on one or more NGSS associated with the LP. The pre- and post-intervention plans also had to be on different selected standards to ensure the post-intervention was just not an updated version of the pre-intervention plan with corrections.

Knowledge Claim

Preservice teachers advanced their PCK in a content-based science education course through their engagement in a LP. The preservice teachers in my study were enrolled in a hybrid content/pedagogy course taught within their teacher education program. The hybrid nature of the course allowed me to design an LP incorporating content while experiencing proper pedagogy, as opposed to the more traditional university science content courses that rely mainly on lecture and focus on content mastery. By developing a LP focused on dinosaurs, I was able to incorporate a high-interest topic (i.e., dinosaurs) for the K-12 students these preservice teachers will eventually serve, while modeling how instruction can be integrated for various science concepts across domains of science in the same lesson. Ultimately, the goal of preservice teacher education is to increase their PCK. My research indicated that engagement in the Dinosaur LP allowed preservice teachers to develop quality lessons, understand more about the Earth and life science content they will teach, and transform their future classrooms into engaging, optimal learning environments that meet the needs of their students.

This research effort begins to fill some of the holes I found in existing research. First, dinosaurs had not been part of the curriculum at all in science education; and second, LPs had not been used in teacher education. With preservice teacher education focusing on the development of PCK, I believe these preliminary findings support the LP as a viable option for achieving this goal.

My new methodology provides a road map for other science education researchers and curriculum developers to develop their own expert-derived and internally valid LPs through ten basic steps. (1) Establish a topic of high-interest as a thematic vehicle for learning. (2) Identify experts in content of thematic vehicle and science education. (3) Interview experts about where the theme can exist within current science classrooms. (4) Transcribe and code interviews to develop concepts of LP. (5) Compare concepts with curriculum standards (i.e., NGSS) to identify areas of emphasis (i.e., Core Ideas). (6) Develop domains that include identified concepts and standards (e.g., big ideas that include multiple standards). (7) Construct a strand map to visualize the vertical alignment and cross domain integration. (8) Identify intermediate knowledge levels, as well as overall knowledge claim the LP will aim to address. (9) Develop student centered learning environments (SCLEs) rooted in authentic science practices that model proper pedagogy for 21st century science learners. (10) Create or find any necessary supplementary learning materials needed for SCLEs.

Aspects regarding the integration of LPs into preservice teacher education have not been reported in researcher- or practitioner-related literature. I focused on how a LP can create conceptual knowledge gains in preservice teachers. Through modeled and simulated lessons across four grade bands, preservice teachers explored various NGSS in a dinosaur thematic LP. Not only did their ability to recognize the importance of a high-interest topic like dinosaurs prevail, but preservice teachers learned science. They learned science concepts through dinosaurs. For example, I taught evolution without ever mentioning Charles Darwin or the Galápagos Islands. At the same time, they integrated previously acquired knowledge Ecology and Genetics & Organisms concepts in the high school grade-band SCLE rooted in the domain of Evolution. This model of teaching preservice teachers science content was not relegated to PowerPoint presentations. Instead, preservice teachers' experiences were hands-on, modeling a 5E lesson style format, and mimicking appropriate grade-band specific teaching.

Ultimately, preservice teachers were able to learn science through doing. No memorization of facts was needed, just good teaching and planning provided through the LP.

Implications for Further Studies

The structure of many preservice programs makes it unreasonable to have preservice teachers teach their own lessons in field placements. A multitude of issues continue to arise in large teacher education programs, including coordination efforts with field placement schools, the variability in expertise of mentor classroom teachers, and the variability of preservice teacher ability. Also, from my experience, preservice teachers have not always been placed with a classroom teacher mentor who teaches the content of the courses in which they were enrolled. To address this issue, the findings in my study provided evidence that preservice teachers were able to develop their PCK without going into the field. I make no attempt here to devalue field placements. Rather, my comments are made to reaffirm the necessity of modeling good teaching and incorporating pedagogy into content coursework.

The unique content-based science education course I taught was offered through the College of Education. It served as a model for science instruction that could be expanded to other courses for preservice teachers offered in colleges of Science and Education. Early attempts were made by the National Science Foundation in the late 20th Century to adapt science courses to meet the needs of preservice teachers [e.g., see Stuessy, 1993]. Other initiatives aimed at reforming the way preservice teachers are taught science have existed in the ensuing years, most of which have expired. One of the most wide-spread initiatives, UTeach, is still in existence (UTeach, n.d.). The UTeach Model has been adopted by many universities around the nation as an alternative to the traditional preparation of mathematics and science teachers. However, it is a very restrictive model limiting the focus of colleges of Education to pedagogy and colleges of Science to content. UTeach universities already have made a commitment to a collaborative process of reforming teacher education. These universities could be likely candidates to pursue the incorporation of LPs and lesson planning in science classes to support preservice teachers' development of PCK within the context of science content courses taught by colleges of Science. However, the UTeach model is primarily for a high school certification, while offering a middle school certification, too. What about traditional colleges of Education? What about elementary preservice teachers? My findings support that colleges of Education can rely on their own instructors with specialized content areas to deliver quality instruction about content to preservice teachers, while still emphasizing pedagogy. The more pedagogy-based courses do not need to sacrifice learning objectives to infuse content if done in a manner where both concentrations are supportive of one another. LPs offer this solution for science education. Preservice teachers of any certification level can learn science content and pedagogical practices simultaneously with the aid of LPs in science education courses that emphasize content and pedagogy equally.

These findings also support the possibility of measuring changes in preservice teacher' PCK through the inclusion of lesson plan development in a content-rich education courses. Using a scoring rubric, such as the 5E ILPv2 developed by Goldston, Dantzler, Day, and Webb (2013), would permit science educators to ensure both pedagogy and content were acceptable in preservice-teacher developed plans. I envision additional studies examining the differences in teachers' methods for designing and implementing lesson plans in courses taught via traditional methods versus courses taught using LPs, thus confirming that LPs not only lead to better lesson plans but also better instructional practices.

Summary

This dissertation study answered the call for PCK developmental needs for preservice teachers, while exploring the use of LPs as an intervention in science education coursework. Rather than delaying lesson planning to a methods-based course, the design of the LP integrated instructional goals of increasing learners' conceptual knowledge gains with their knowledge of pedagogy practices. I established a framework for LP development for other science educators aiming to answer the call for more LP research. The framework established for expert-derived LPs offers a process that is replicable and can be utilized for developing LPs for K-12 learners for preservice teachers. This dissertation study ultimately supported the integration of LPs into science education coursework as resulting in significant PCK development of preservice teachers.

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APPENDIX A

STANDARDS OF DINOSAUR LEARNING PROGRESSION*

Grades K-2 Elementary Standards

Life Sciences

Grades K-2-LS1 From Molecules to Organisms: Structures and Processes.

K-LS1-1. Use observations to describe patterns of what plants and animals (including humans) need to survive. [Clarification Statement: Examples of patterns could include that animals need to take in food but plants do not; the different kinds of food needed by different types of animals; the requirement of plants to have light; and, that all living things need water.]

1-LS1-1. Use materials to design a solution to a human problem by mimicking how plants and/or animals use their external parts to help them survive, grow, and meet their needs.*[Clarification Statement: Examples of human problems that can be solved by mimicking plant or animal solutions could include designing clothing or equipment to protect bicyclists by mimicking turtle shells, acorn shells, and animal scales; stabilizing structures by mimicking animal tails and roots on plants; keeping out intruders by mimicking thorns on branches and animal quills; and, detecting intruders by mimicking eyes and ears.]

1-LS1-2. Read texts and use media to determine patterns in behavior of parents and offspring that help offspring survive. [Clarification Statement: Examples of patterns of behaviors could include the signals that offspring make (such as crying, cheeping, and other vocalizations) and the responses of the parents (such as feeding, comforting, and protecting the offspring).]

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Grades K-2-LS3 Heredity: Inheritance and Variation of Traits.

1-LS3-1. Make observations to construct an evidence-based account that young plants and animals are like, but not exactly like, their parents. [Clarification Statement: Examples of patterns could include features plants or animals share. Examples of observations could include leaves from the same kind of plant are the same shape but can differ in size; and, a particular breed of dog looks like its parents but is not exactly the same.] [*Assessment Boundary: Assessment does not include inheritance or animals that undergo metamorphosis or hybrids.*]

Grades K-2-LS4 Biological Evolution: Unity and Diversity.

2-LS4-1. Make observations of plants and animals to compare the diversity of life in different habitats. [Clarification Statement: Emphasis is on the diversity of living things in each of a variety of different habitats.] [*Assessment Boundary: Assessment does not include specific animal and plant names in specific habitats.*]

Earth and Space Sciences

Grades K-2-ESS1 Earth’s Place in the Universe.

2-ESS1-1. Use information from several sources to provide evidence that Earth events can occur quickly or slowly. [Clarification Statement: Examples of events and timescales could include volcanic explosions and earthquakes, which happen quickly and erosion of rocks, which occurs slowly.] [*Assessment Boundary: Assessment does not include quantitative measurements of timescales.*]

Grades K-2-ESS1 Earth’s Systems.

K-ESS2-2. Construct an argument supported by evidence for how plants and animals (including humans) can change the environment to meet their needs. [Clarification Statement: Examples of plants and animals changing their environment could include a squirrel digs in the ground to hide its food and tree roots can break concrete.]

2-ESS2-1. Compare multiple solutions designed to slow or prevent wind or water from changing the shape of the land.* [Clarification Statement: Examples of solutions could include different designs of dikes and windbreaks to hold back wind and water, and different designs for using shrubs, grass, and trees to hold back the land.]

Grades K-2-ESS3 Earth and Human Activity.

K-ESS3-1. Use a model to represent the relationship between the needs of different plants and animals (including humans) and the places they live. [Clarification Statement: Examples of relationships could include that deer eat buds and leaves, therefore, they usually live in forested areas; and, grasses need sunlight so they often grow in meadows. Plants, animals, and their surroundings make up a system.]

Grades 3-5 Elementary Standards

Life Sciences

Grades 3-5-LS1 From Molecules to Organisms: Structures and Processes.

3-LS1-1. Develop models to describe that organisms have unique and diverse life cycles but all have in common birth, growth, reproduction, and death. [Clarification Statement: Changes organisms go through during their life form a pattern.] [*Assessment Boundary: Assessment of plant life cycles is limited to those of flowering plants. Assessment does not include details of human reproduction.*]

4-LS1-1. Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction. [Clarification Statement: Examples of structures could include thorns, stems, roots, colored petals, heart, stomach, lung, brain, and skin.] [*Assessment Boundary: Assessment is limited to macroscopic structures within plant and animal systems.*]

Grades 3-5-LS2 Ecosystems: Interactions, Energy and Dynamics.

3-LS2-1. Construct an argument that some animals form groups that help members survive. [No Clarification Statement]

Grades 3-5-LS3 Heredity: Inheritance and Variation of Traits.

3-LS3-1. Analyze and interpret data to provide evidence that plants and animals have traits inherited from parents and that variation of these traits exists in a group of similar organisms. [Clarification Statement: Patterns are the similarities and differences in traits shared between offspring and their parents, or among siblings. Emphasis is on organisms other than humans.] [*Assessment Boundary: Assessment does not include genetic mechanisms of inheritance and prediction of traits. Assessment is limited to non-human examples.*]

3-LS3-2. Use evidence to support the explanation that traits can be influenced by the environment. [Clarification Statement: Examples of the environment affecting a trait could include normally tall plants grown with insufficient water are stunted; and, a pet dog that is given too much food and little exercise may become overweight.]

3-5-LS4 Biological Evolution: Unity and Diversity.

3-LS4-1. Analyze and interpret data from fossils to provide evidence of the organisms and the environments in which they lived long ago. [Clarification Statement: Examples of data could include type, size, and distributions of fossil organisms. Examples of fossils and environments could include marine fossils found on dry land, tropical plant fossils found in Arctic areas, and fossils of extinct organisms.] [*Assessment Boundary: Assessment does not include identification of specific fossils or present plants and animals. Assessment is limited to major fossil types and relative ages.*]

3-LS4-2. Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving, finding mates, and reproducing. [Clarification Statement: Examples of cause and effect relationships could be plants that have larger thorns than other plants may be less likely to be eaten by predators; and, animals that have better camouflage coloration than other animals may be more likely to survive and therefore more likely to leave offspring.]

3-LS4-3. Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all. [Clarification Statement: Examples of evidence could include needs and characteristics of the organisms and habitats involved. The organisms and their habitat make up a system in which the parts depend on each other.]

3-LS4-4. Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.* [Clarification Statement: Examples of environmental changes could include changes in land characteristics, water distribution, temperature, food, and other organisms.] [*Assessment Boundary: Assessment is limited to a single environmental change. Assessment does not include the greenhouse effect or climate change.*]

Earth and Space Sciences

3-5-ESS1 Earth's Place in the Universe.

4-ESS1-1. Identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time. [Clarification Statement: Examples of evidence from patterns could include rock layers with marine shell fossils above rock layers with plant fossils and no shells, indicating a change from land to water over time; and, a canyon with different rock layers in the walls and a river in the bottom, indicating that over time a river cut through the rock.] [*Assessment Boundary: Assessment does not include specific knowledge of the mechanism of rock formation or memorization of specific rock formations and layers. Assessment is limited to relative time.*]

Middle School Standards

Life Sciences

MS-LS1 From Molecules to Organisms: Structures and Processes.

MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms. [Clarification Statement: Examples of local environmental conditions could include availability of food, light, space, and water. Examples of genetic factors could include large breed cattle and species of grass affecting growth of organisms. Examples of evidence could include drought decreasing plant growth, fertilizer increasing plant growth, different varieties of plant seeds growing at different rates in different conditions, and fish growing larger in large ponds than they do in small ponds.] [*Assessment Boundary: Assessment does not include genetic mechanisms, gene regulation, or biochemical processes.*]

MS-LS2 Ecosystems: Interactions, Energy, and Dynamics.

MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. [Clarification Statement: Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.]

MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. [Clarification Statement: Emphasis is on recognizing patterns in data and making warranted inferences about changes in populations, and on evaluating empirical evidence supporting arguments about changes to ecosystems.]

MS-LS3 Heredity: Inheritance and Variation of Traits.

MS-LS3-1. Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism. [Clarification Statement: Emphasis is on conceptual understanding that changes in genetic material may result in making different proteins.] [*Assessment Boundary: Assessment does not include specific changes at the molecular level, mechanisms for protein synthesis, or specific types of mutations.*]

MS-LS4 Biological Evolution: Unity and Diversity.

MS-LS4-1. Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past. [Clarification Statement: Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [Assessment Boundary: Assessment does not include the names of individual species or geological eras in the fossil record.]

MS-LS4-2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships. [Clarification Statement: Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarity or differences of the gross appearance of anatomical structures.]

MS-LS4-4. Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment. [Clarification Statement: Emphasis is on using simple probability statements and proportional reasoning to construct explanations.]

Earth and Space Sciences

MS-ESS1 Earth's Place in the Universe.

MS-ESS1-4. Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history. [Clarification Statement: Emphasis is on how analyses of rock formations and the fossils they contain are used to establish relative ages of major events in Earth's history. Examples of Earth's major events could range from being very recent (such as the last Ice Age or the earliest fossils of homo sapiens) to very old (such as the formation of Earth or the earliest evidence of life). Examples can include the formation of mountain chains and ocean basins, the evolution or extinction of particular living organisms, or significant volcanic eruptions.] [*Assessment Boundary: Assessment does not include recalling the names of specific periods or epochs and events within them.*]

MS-ESS2 Earth's Systems.

MS-ESS2-2. Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind.]

MS-ESS2-3. Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions. [Clarification Statement: Examples of data include similarities of rock and fossil types on different continents, the shapes of the continents (including continental shelves), and the locations of ocean structures (such as ridges, fracture zones, and trenches).] [*Assessment Boundary: Paleomagnetic anomalies in oceanic and continental crust are not assessed.*]

High School Standards

Life Sciences

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics.

HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] [*Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.*]

HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. [Clarification Statement: Emphasis is on using a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and that matter and energy are conserved as matter cycles and energy flows through ecosystems. Emphasis is on atoms and molecules such as carbon, oxygen, hydrogen and nitrogen being conserved as they move through an ecosystem.] [*Assessment Boundary: Assessment is limited to proportional reasoning to describe the cycling of matter and flow of energy.*]

HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

HS-LS2-8. Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce. [Clarification Statement: Emphasis is on: (1) distinguishing between group and individual behavior, (2) identifying evidence supporting the outcomes of group behavior, and (3) developing logical and reasonable arguments based on evidence. Examples of group behaviors could include flocking, schooling, herding, and cooperative behaviors such as hunting, migrating, and swarming.]

HS-LS3 Heredity: Inheritance and Variation of Traits.

HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. [*Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.*]

HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: ~~(1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or~~ (3) mutations caused by environmental factors. [Clarification Statement: Emphasis is on using data to support arguments for the way variation occurs.] [Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.]

HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population. [Clarification Statement: Emphasis is on the use of mathematics to describe the probability of traits as it relates to genetic and environmental factors in the expression of traits.] [*Assessment Boundary: Assessment does not include Hardy-Weinberg calculations.*]

HS-LS4 Biological Evolution: Unity and Diversity.

HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. [Clarification Statement: Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.]

HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment. [Clarification Statement: Emphasis is on using evidence to explain the influence each of the four factors has on number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [*Assessment Boundary: Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and co-evolution.*]

HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.[Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [*Assessment Boundary: Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.*]

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations. [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]

HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in:(1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. [Clarification Statement: Emphasis is on determining cause and effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.]

Earth and Space Sciences

HS-ESS1 Earth's Place in the Universe.

HS-ESS1-5. Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks. [Clarification Statement: Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks. Examples include evidence of the ages oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of North American continental crust decreasing with distance away from a central ancient core of the continental plate (a result of past plate interactions).]

HS-ESS2 Earth’s Systems.

HS-ESS2-7.	Construct an argument based on evidence about the simultaneous coevolution of Earth’s systems and life on Earth. [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth’s other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth’s surface. Examples of include how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.] [*Assessment Boundary: Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth’s other systems.*]

APPENDIX B

USING EXPERTS TO VALIDATE SCIENCE DOMAIN CONTENT IN A DINOSAUR LEARNING PROGRESSION*

A strand map of the dinosaur learning progression accompanies this dissertation in a large file format PDF. This separate attachment shows the NGSS, the relationships between the standards, organization by domain (i.e., Ecology, Evolution, Genetics & Organisms, Geology) and progression through grade bands (i.e., K-2, 3-5, Middle School, High School). Structure of the strand map is adopted from the *Atlas for Science Literacy* (AAAS, 2000).

*Reprinted and rearranged with permission NGSS Lead States. 2013. *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press. Copyright 2013 by NGSS Leads States.

APPENDIX C

COMPREHENSIVE LITERATURE REVIEW

Imagine a high school science teacher beginning to teach a unit on Evolution. His students are typical ninth graders, distributed in six classes of about 24 students each. Demographically, about two-thirds of his biology students have been labelled by the school district as being “socioeconomically disadvantaged.” Overall, the teacher knows that reading comprehension is particularly difficult for most of his students, a concern as state-mandated testing in all freshmen subjects relies heavily on students’ abilities to make sense of text. By introducing scientific articles, the teacher hopes to increase his students’ abilities to make sense of unfamiliar text.

The teacher begins the introductory lesson by asking students, who normally work in self-regulated groups of two to four, to view a diagram from *Scientific American* (Brusatte, 2017, pp. 52-53). He distributes a copy of the article to every student in the class and explains that the diagram tracks the author’s latest ideas about the origin of birds from dinosaurs. He then provides students with the in-class assignment: “Please examine the diagram carefully. Talk with the members of your group to come up with a scientific argument. Support your argument about the transformation of dinosaurs into birds with the diagram and reading.” Students then examine the diagram carefully to generate a list of facts represented in the author’s diagram. After about 25 minutes, the teacher notes that students’ attentions are wandering and they appear to have completed their discussions. He calls the class together and asks each group to share its lists. The teacher uses the group presentations of their lists to lead a discussion about the value of diagrams such as this one in delivering scientific information in condensed form, about the specific information students have gleaned from the diagram.

The teacher then refers students to the written text of the article and asks them to scan the article overnight, with special attention to one section of the article he has assigned to each group. He explains that those assigned pages and paragraphs create an episode for which they will be responsible in tomorrow's class activity. He explains that tomorrow in class each group will plan how they will act out the assigned part of the article and act out the "mini-episode" the following day. To bring students back into class he makes use of a TED Talk, *Where are the baby dinosaurs?* to get students to question what they learned the day prior about speciation and cladistics (Horner, 2011). Students proceed to discuss the topic of the video and their reading with the class before planning their "mini-episode."

This teacher's translation of science content knowledge into a series of lesson plans reveals an advanced level of pedagogical content knowledge. If I were asked to evaluate his teaching, I would note several things from this scenario. First, the teacher used students' interests in dinosaurs to introduce a new unit of instruction. He also translated conceptual knowledge accurately into innovative teaching practice. The teacher created groups to support students with learning deficiencies and heterogeneous mixing of students within groups to allow for peer support and encourage collaboration. These practices, as well as, the incorporation of a diagram to help with reading difficulties, technology to engage learners, integrated science content across multiple topics of biology, and active engagement by students in developing mini-episodes, all student-centered learning activities reflecting a high level of pedagogical content knowledge.

My Background

High School Science Teaching

I began my teaching career at a high school in rural central Texas with an enrollment of around 750 students. The demographics of the high school reflected the district composition. District-wide, 77.5% of the student population was classified as economically disadvantaged (TEA, 2012). The demographics of the high school included 45% Hispanic, 28% White, and 26% African American students. Only 63.3% of the students enrolled to take college entrance examinations, with a mere 14.3% of students testing at or above criterion set by the Texas Education Agency.

The school experienced a relatively high (18.3%) teacher turnover; about half (43.3%) of all teachers had less than five years of teaching experience. Every year this school hired new teachers who were often ill-prepared to teach the subject assigned to them. They came with one of two deficiencies: either their pedagogical practices were insufficient or their conceptual understanding of the subject matter was lacking. In science, some of our strongest high school teachers had bachelor's degrees in hard science concentration areas, but often their pedagogy was unsophisticated. These teachers paid no attention to the characteristics of the learners for whom they were responsible. Other science teachers, however, were prepared with a degree in "composite science" with little depth of knowledge in any science content area; or they had used an alternate certification route that substituted classroom teaching experience for rigorous content course requirements.

I learned in my teacher preparation program that teaching science was not only about the content; science literacy was the goal. A much bigger goal than memorizing inert factual information, science literacy led students to understanding about science as a way of knowing and finding about their world. Science literacy is not just about higher test scores, although that is our common measurement, but it is about students owning their knowledge in science and being able to apply it in their life. As stated in *Science for All Americans*, "To neglect the science education of any (as has happened too often to girls and minority students) is to deprive them of a basic education, handicap them for life…a loss the nation can ill afford" (AAAS, p. 214, 1994). Furthermore, scientifically literate students are not as likely to avoid science education or careers (AAAS, 1994). In my school, however, it did not take long for me to realize that most of the science teachers with whom I taught had not received the sort of training that leads students to respect or use scientific knowledge or skills in living, learning, and making decisions. Unfortunately, many high school teachers at my school neither possessed nor valued the pedagogical skills that could engage students' interests and transform their understanding of the world around them.

In my first years of teaching, I realized that my teacher preparation was unique in its focus: developing reformed ways of thinking about the value of science literacy in a technology-advanced, rapidly changing, 21st century world. My teacher program reinforced the importance of making learning meaningful to my students, to use topics that fascinated my students, especially when introducing complex, unfamiliar scientific information. For example, I found that dinosaurs was a topic of interest for a lot of my high school students. Many of them had even asked why they had never learned about these prehistoric creatures in school. Much like the teacher in the vignette introducing this chapter, I crafted my evolution unit around dinosaurs to better engage my students in the scientific topics of natural selection, cladistics, genetics, and classification. Over my years of teaching, I realized that an introduction focusing on dinosaurs led to students enthralled with evolution, even though the community served by my school was known to be ultra-conservative and viewed evolution as a topic of controversy. Dinosaurs had been a key for me in introducing evolution to my students as an exciting, natural mechanism by which organisms changed over time.

My baccalaureate in biology prepared my content knowledge. A Master's in curriculum and instruction instilled pedagogical methodologies theoretically ideal for a K-12 classroom. Pedagogical courses associated with my Master's worked impacted and transformed content knowledge into pedagogical content knowledge (PCK), which is a very specialized type of knowledge unique to teachers. PCK is teacher knowledge that enables the classroom teacher to translate content knowledge into meaningful learning experiences. My PCK was initially impacted by my preparation courses. However, classroom teaching instruction and internal reflection enhanced my understanding of what to teach and how to teach it effectively to novice learners. Effective practices shaping my PCK included facilitating lessons rather than disseminating information, promoting autonomous group work within learning activities, fostering an environment of active learners, and slowing down the curriculum incorporate time for contemplation among my students. While my abilities to combine pedagogy and content knowledge grew stronger through teaching high school biology, classroom teaching was not the only thing affecting the evolution of my PCK. Working with peers within a community, learning to navigate state and national standards, and knowing how I could use curriculum materials to develop rich conceptual understanding in my students all had a positive impact.

University-Based Science Teaching

My transition from teaching high school led to teaching university preservice teachers, which proved to be a very different experience for me. First, the goals of my instruction were different. In high school teaching, my focus was based on my students' achievement of scientific literacy. In college teaching, the focus was still on the development of science literacy, but I also had to focus on facilitating my students' abilities to transform their science knowledge into teaching. In high school teaching, I emphasized proper scientific practices. In college teaching, I was challenged also to facilitate my students' development of PCK. I had two emphases to develop a high level of PCK in preservice teachers. First, I focused on the development of classroom instructional strategies and second, I focused on preservice teachers' translation and use of science content knowledge.

Teaching science courses to preservice teachers also continued to transform my PCK, which addressed the specialized needs of preservice teachers. My own teaching was transformed to model methodologies promoting student-centered learning and integrated approaches reflecting real-world rather than textbook-based science. I also modeled authentic science practices whenever possible and provided preservice teachers with classroom examples. Authentic science practices included asking questions, defining problems, constructing models, planning and implementing investigations, and using evidence to support scientific arguments (NGSS Leads States, 2013).

My assessments were also more complex. I tested my students' abilities to both conceptualize content knowledge in specific domains and to develop lesson plans reflecting pedagogy presented through methods coursework. All of these qualities are prerequisite to preservice teachers' development of PCK, which goes far beyond focusing on enhancing what students know to extend the focus on how my students would use their knowledge to transform it into what they would teach to school children. The times I have spent teaching high school biology and preservice teachers are just about the same. The biggest change, however, has been the additional emphasis on *how to teach*. Have my students enter the workforce with the beginning of a well-developed PCK has been the objective of my college teaching.

Getting There: Pedagogical Content Knowledge

A teacher's professional development is neither the result of training nor of policy. Teachers develop professional knowledge by learning from their teaching and interactions with their students and by their extrapolation of techniques from training (Wallace & Loughran, 2012). PCK not only refers to how teachers apply their knowledge of how to teach, but how their content knowledge is incorporated into their teaching. Cochran (1997) states PCK is “the integration or the synthesis of teachers’ pedagogical knowledge and their subject matter knowledge” (p.97). Teaching is more than disseminating knowledge to students. Teaching requires a finesse of facilitating new information so that it can connect to mental threads of the past and open possibilities for new connections in the future. Teaching is an unending journey of theory into practice.

One method for development of PCK is to practice reflection. A teacher’s PCK is only accessible and usable once it is conceptualized (Wallace & Loughran, 2012). Reflection on self-development of PCK aids in the construction of a complete preservice teacher development (Nilsson & Loughran, 2012). Novak and Gowin (1984) suggest that linking concepts together to make propositions of knowledge structure create conceptual relationships of knowledge in the learner’s mind. Researchers (Nilsson & Loughran, 2012; Reitano & Green, 2013; Demirdöğen, Aydin, & Tarkin, 2015) have observed that reflection and recognition of PCK growth positively impacts preservice teacher learning.

Typically, college science courses are organized in a teacher-directed, lecture-based manner that promotes a dissemination of knowledge by the professor. Most science content coursework required for preservice teachers comes from a medley of courses that are not geared towards preparing teachers (Lyons et al., 2015). A reliance on college coursework is a weak structure for preparing future science teachers (Lederman, Gess-Newsome, & Latz, 1994). Methods and other education courses attempt to connect prerequisite knowledge with teaching theory. In a research study focusing on preservice teachers in a science methods course, data indicated that a focus on content led to gains in content knowledge (Santau, Maerten-Rivera, Bovis, & Orend, 2014). Prior to the study, most of the preservice teachers' science coursework was in life science subjects. After the twelve inquiry-based lessons were incorporated into the methods course, preservice teachers showed gains in life, physical and earth sciences content. The research team suggested conceptual knowledge across science domains was fostered with a more intent focus on science content through student-centered learning. Other researchers have investigated the use of tools in the manner of prompts to help preservice teachers better recognize their development of PCK (Nilsson & Loughran, 2012). Preservice teachers stated that this recognition helped them produce more authentic science lessons. These authentic science lessons included skills and necessary processes (i.e., inquiry, scientific argumentation based on evidence) to represent science in a purer form. Outside of science, a study of beginning history teachers examined the use of concept maps to advance PCK (Reitano & Green, 2013). The practice of reflection and use of concept maps produced a maturation in PCK in preservice teachers, even though the concept maps were unique to each participant in the study.

Lesson development and maturation of teaching practices are important areas of concentration in preservice teacher education. Transforming epistemology into pedagogy is a vital element assuring success of preservice teachers in their advanced methods placements and future classrooms. The *Next Generation Science Standards*

(NGSS) call for classroom practices that incorporate inquiry, problem-based investigations and engineering design (NGSS Leads States, 2013). The foundation of these principles, along with cross-cutting concepts (i.e., patterns, cause and effect, scale, models, systems, structure and function, stability and change), are necessary for developing student-centered learning. Van Driel, Jong and Verloop (2002) found that the cognizance of preservice teachers was primarily developed during teaching practices. When preservice teachers were more aware of issues in student learning and weaknesses in conceptualization, they were better able to adjust their pedagogy accordingly. More focused consideration on particular science practices (e.g., argumentation) in teacher training has shown to be effective for increasing the teachers' ability and likelihood of using science practices in an authentic manner (McNeill & Knight, 2013). Teachers have a propensity to teach in sections, while integration of topics and comparative analysis may prove to better support student concept making (Nilsson, 2014). In a ten-week study of three science teachers, a focus and critical breakdown of the learning struggles of their students revealed that metacognitive reflections of teaching practices were affected by PCK. This finding suggests that a self-aware analysis of PCK during teacher development could influence how teachers prepare lessons and enact strategies.

Authentic Lesson Plans

While lesson plans are a traditional tool in the arsenal of prepared teachers, extreme differences can exist in their design and implementation. Such extreme differences are apparent in "authentic" science lesson plans as compared with traditional lesson plans for delivering inert scientific information. The latter type of plan models traditional methods typical of many university science courses. Authentic science lessons, in contrast, rely heavily on the incorporation of authentic science practices. To develop scientifically literate students, lesson plans incorporate activities that promote the asking of questions, problem solving, planning and conducting investigations, crafting scientific arguments rooted in evidence, the ability to analyze data, and the ability to evaluate and communicate information. Authentic science lessons are also multidimensional in their focus on content. Authentic to the world in which students live and work, authentic lesson plans incorporate crosscutting concepts. They are not bound by any one domain of science; instead, concepts cut across all science domains to include ideas about structure and function, scale, patterns, systems, cause and effect, stability and change, and energy and matter (NGSS Leads States, 2013). Finally, another aspect of authenticity is that the lesson plan properly represents science content. For example, a research study investigating teacher lessons plans revealed that elementary teachers with access to accurate science teaching materials were better able to authentically represent the science concepts to their students (Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2013). Furthermore, understanding common misconceptions held by students about how the world works (e.g., that the sun does actually rise and set) of what students are learning better prepares teachers to design lessons specifically to address students' misconceptions (Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2016).

The ultimate in the authentic science lesson plan, however, comes from the design of lessons that provide opportunities for students to do science just as scientists do. Edelson, Gordin, and Pea (2011), for example, provided an excellent description of such lessons with helpful hints to teachers about adapting actual scientific experiments for SCLEs in the classroom. Suggestions from the researchers include designing lessons that provide a motivational context, sequence activities to support learning, and incorporate proper investigation tools to create a supportive learning environment "assembled into a coherent whole" (Edelson, Gordin, & Pea, 2011, p. 444). Bonnstetter (1998) provided descriptions of different styles of science lessons from traditional hands-on to student research. He offered suggestions about who (i.e., teacher, student) develops the topic, question, materials, procedure, results, analysis, and conclusions. Bonnstetter explained traditional hands-on as the typical "cookbook" lab where the teacher provides everything. He placed authentic scientific practices beyond "guided" instruction, because the student is responsible in all phases of learning, except for topic generation. This promotion of inquiry supported inclusion of authentic science practices in lesson plans. Chinn and Malhotra (2002), as well, suggested that inquiry tasks designed for students do not often reflect authentic science practices, but exist instead as student-driven, basic, laboratory explorations. Authentic practices identified by Chinn and Malhotra were mirrored the NGSS science practices, which were produced several years after the Chinn and Malhotra article. Current reform movements in science education stress the importance of preservice teachers' experiencing authentic science. If preservice teachers are provided learning opportunities that limit the system, they will be unable to conceptualize science lessons that reflect authenticity (Hmelo, Holton, Kolodner, 2000). As a result, future students of current cohorts of preservice teachers will join other generations of students suffering from antiquated, non-authentic science lessons that do not promote scientific literacy.

Student-centered instruction is not a new concept. Learning cycles with students first are not a new revelation, but have been around for over 80 years. As early as 1930s, Dewey replaced the teacher-centric Herbart's instructional model that had been used for over a century with student-centered notions of teaching. The addition of perplexing situations, Dewey suggested, would create lessons that would get students invested and interested in learning. Student-centered lessons with a focus on student exploration were introduced in the 1950s (Heiss, Oborun, & Hoffman, 1950). By the early 1960s, a partnership between Robert Karplus and J. Myron Atkin led to the development of the "guided discovery" model of learning. The terms "exploration," "invention," and "discovery" were used by Karplus and Atkin to describe the phases of student learning. Expanded by the Biological Science Curriculum Study (BSCS) in the 1980s, these three phases would then morph into a lesson plan cycle known as The BSCS 5E Instructional Model (Bybee et al., 2006).

The BSCS 5E Instructional Model includes five phases: Engagement, Exploration, Explanation, Elaboration, and Evaluation (Bybee et al., 2006). Exploration in the Karplus and Atkin model would now be preceded by Engagement; and Discovery (now Elaboration) would be followed by Evaluation (see Figure 3). The BSCS 5E Instructional Model is grounded in research and supported by education theories developed by Piaget and Vygotsky. The five phases of this instructional model have various purposes, which are clarified in Table 15.

The BSCS 5E Instructional Model provides an excellent template for designing, implementing, and evaluating authentic science lessons. Teacher educators can progress PCK by tasking preservice teachers with crafting authentic 5E lesson plans (Goldston, Day, Sundberg, & Dantzler, 2010). Supporting the development of these plans with proper instruction reflects what is to be expected of preservice teachers in their first classrooms. Goldston, Dantzler, Day, and Webb (2013) have developed a valid and reliable rubric that can be used to measure how well preservice teachers are constructing 5E lesson plans. With the structure of the BSCS 5E Instructional Model and the 5E Inquiry Lesson Plan Version 2 Rubric, it is possible to measure the progression of preservice teacher PCK development as it pertains to lesson planning.

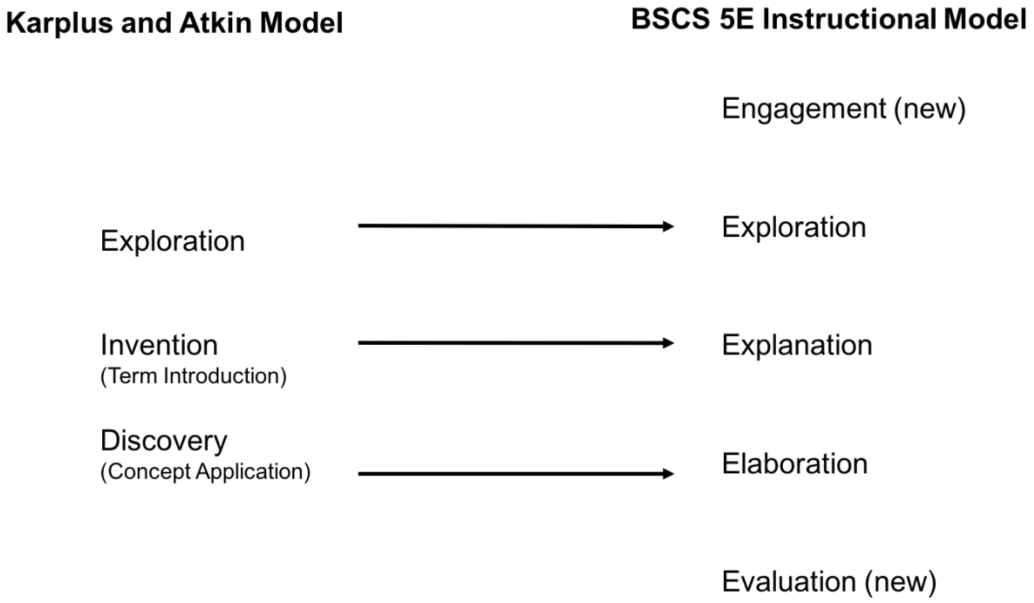

Figure 3. Emergence of 5E model. This schematic illustrates the change from Karplus and Atkin model of instruction to the BSCS 5E Instructional Model. (After *Perspectives on Activity Theory* (p. 13) by Bybee et al., 2006, Colorado Springs, CO: Biological Science Curriculum Study.

Table 15

Operational Definitions of BSCS 5E Instructional Model Phases

Phase	Operational Definition
Engagement	Assesses prior knowledge, promotes curiosity, organizes students' thinking towards learning outcomes, gets students motivated for learning activity
Exploration	Provides student-centered activities to promote hands-on and minds-on learning, promotes investigation, requires learners to utilize prior knowledge
Explanation	Teachers facilitate student responses about prior phases, connects exploration, concepts become clear and are presented in a direct and brief manner
Elaboration	Provides students the opportunity to connect concepts to new areas, relates activities to real-life, transfer of concept and skills to new situations
Evaluation	Students should receive feedback from prior phases, refers to summative evaluation, informal evaluations are embedded throughout lesson, must match lesson objectives, should be clear and measurable

Note. Adapted from Bybee et al., 2006 and Goldston, Dantzler, Day, & Webb (2013).

Concept Maps

Teachers can use concept mapping to create a learning environment conducive to the conceptualization of subject-specific content (Novak, 1998). Concept maps are visual representations of "meaningful relationships between concepts" (Novak & Gowin, 1984, p. 15). Concept maps allow for the creator of the map to build and communicate associations between ideas and to define their affiliations through linking phrases that complete the thought. A classroom supporting conceptual learning allows students to make sense of their learning. Conceptual learning occurs in authentic lessons incorporating negotiation, hands-on activities, authentic practices, and crosscutting concepts. Novak (1998) suggested that context is also a critical aspect of how students learn. Any created concept map by a learner situates his/her conceptual understanding based on the context of how it was delivered through instruction. If learning environments are established to be student-centered, scaffolded around appropriate content and supported through proper pedagogy, then conceptualization of material is facilitated.

Novak (1984) provided a method for scoring hierarchical concept maps by assigning points to specific levels of the map. Varying amounts of point are awarded for meaningful propositions between two concepts linked by appropriate linking phrases, proper hierarchy, valid crosslinks across the map, and appropriate examples. Scoring maps provides an opportunity for quantitative analysis by examining the visual representations of what learners comprehend about a subject.

Concept maps can be used for evaluation by teachers (Novak, 1998). To ensure a proper construction of ideas, teachers can limit student misconceptions through authentic lessons. Teachers can also help themselves and their students by facilitating the creation of hierarchical maps that progress from the most general idea to specific examples. Grounded in constructivist learning theory, concept maps offer a way for teachers to understand how their students are building knowledge in their minds. Teachers must be aware, however, to limit variations of concept maps to ensure more reliability in assessment (Ruiz-Primo & Shavelson, 1996). Limitations may include rules for map construction, including number of concepts, arrangement of concepts into hierarchical rather than linear arrangements, and providing a list of concepts prior to map construction. Another consideration is to keep concept mapping simple, as too many concepts may limit students' ability to create meaningful connections and require too much class time (McClure, Sonak, & Suen, 1999). Furthermore, providing a process of steps to follow can limit variations.

Increasing Pedagogical Content Knowledge in Preservice Teacher Education

Increasing PCK and the ability to apply PCK are not the same. Both the acquisition and use of PCK should be considered in preservice teacher education. Carrier (2012) found that preservice teachers could increase their scientific knowledge through deliberate coursework, but their capability to properly employ science terms was inconsistent. Preservice teacher education fails to produce scientifically literate teachers without a focus on content and pedagogy. Having preservice teachers analyze lesson plans has shown to that proper curriculum development skills are lacking and additional studies must examine this ability (Beyer & Davis, 2012).

Duit and Treagust (2011) suggest that future studies go beyond development research with an emphasis on conceptual change are a necessity. With regard to conceptual change, they also propose that studies use mixed methods approaches, be more attentive to the context of learning and examine multidimensional perspectives (i.e., epistemological, ontological and affective). Changing a teacher's viewpoint of how to teach is difficult (Duit & Treagust, 2003), thus awakening preservice teachers to how their students will learn through their teaching methods is essential. A focus on the use of PCK on curriculum and instruction planning is necessary to understand how preservice teachers use what they know about science and teaching to create authentic science lessons.

Teaching as They Were Taught

"Teaching the way they were taught" is a saying that often refers critically to teachers who use limited pedagogical knowledge to teach science (Oleson & Hora, 2014). Learning science in a "traditional" manner can translate to science teachers having "traditional beliefs" that closely align to their practices in the classroom (Tsai, 2002). Hancock and Gallard (2004) found that "students learn science through experiences to develop understanding and memorization of information transmitted via lectures" (p. 289).

The saying fits with a middle school science teacher, for example, who emulates her university science professors when she produces a lesson plan that outlines the learning experiences for her classroom of students. With no experience and little knowledge of other ways to design an authentic learning environment for middle-school aged children, the teacher chooses to plan her science lessons around lecture, a teacher-centered pedagogy. With her mentor who observes her class, she reflects on the hours of preparation time she has spent choosing just the right PowerPoint slides to illustrate the major points of the lecture. She believes that her lesson is well prepared. As class begins, the mentor notes that the classroom learning environment the teacher designed for her students aligns well with her teacher-centered perspective. Students sit in desks arrange in rows; the teacher stands in front of the class and refers to her PowerPoint slides at appropriate times during the lecture. The teacher requires students to take notes during lecture and to answer rhetorical, one-word answers to questions during a short burst of “discussion.” This “discussion time” serves to bring students’ attention back to the lecture and away from day-dreaming. She closes the lesson by reminding students to study for tomorrow’s quiz. The next day, she assesses students’ learning by calculating percentages of the correct responses on a set of ten multiple-choice quiz questions.

The mentor notes that the observed aspects of this teacher’s conceptions of learning environments reflect the typical teacher-centered way most university professors teach their science classes. She used a traditional instruction model generally referred to as transmissive instruction, with information communicated from the teacher to her learners. Based on a communications model of instruction, the teacher believes that she is an effective communicator and that her students will understand and “come to know the world as the teacher does” (Jonassen & Land, p. iii, 2000).

Are there times when teaching as they were taught can be a good thing? In some instances, the answer can be “yes.” It all depends on how they were taught. Coursework that links theory and practice through the modeling of “good teaching” is desirable (Darling-Hammond, 2006). Some preservice teachers prefer a student-centered approach to learning and teaching with a focus on the needs and interests of the students (Hancock & Gallard, 2004). These preservice teachers, who could also be described as “teaching the way they were taught,” demonstrated positive outcomes in PCK. The PCK used by their instructors in designing learning experiences was modeled in a way that was as appropriate for preservice teachers as it would be for public school students who would eventually be taught by those preservice teachers. By learning scientific content the way their students would learn, preservice teachers engage in learning the same way that their students would engage: they would perform the same actions, create the same objects (learning products) and, hopefully, reach the same outcomes in terms of content knowledge that their student would reach. By learning how to teach that content, preservice teachers wo engage in the same activities as their students would extend their learning to include reflection, transfer, and reconstruction of their learning to include new experiences similar to the ones they have just experienced.

Student-Centered Learning and PCK

Pedagogical Content Knowledge (PCK) of preservice science teachers includes alignments to multiple components of teaching science. Understanding curricula materials and standards (e.g., NGSS) help shape preservice teachers' knowledge, as well as the information that is presented to them in coursework. This coursework usually highlights strategies for teaching, which may include favorable science methodologies like inquiry or project-based learning. Course objectives at the university, curriculum materials encountered and standards that are reflected for preservice teachers in teacher certification exams are not the only impacts on PCK. Peer interactions in courses that employ student-centered engagement lead to socio-cognitive changes. The roles that preservice teachers assume during learning activities in course and field work aid in the development of a richer PCK. The production of objects (i.e., lesson plans), the exchange of ideas in class, the distribution of tasks in a learning environment all lead to the consumption of activity. Through student-centered activity in the college classroom, teacher educators can impact preservice teacher PCK.

Student-centered learning environments (SCLEs) enable teachers to facilitate acquiring knowledge through activities that lead to construction through embedded experiences (Jonassen & Land, 2000). Situated learning that is distributed across learners embodies the principles of scientific inquiry and discovery. No longer should students be constrained to a disembodied, objective learning environment; Instead, experiential learning practices are suggested for the promotion of authentic science learning (Designs, 2000; S-CBSCS, 2009; NGSS Leads States, 2013).

While promotion of a student-centered epistemology and pedagogy are being installed in K-12 schools throughout the United States, universities still widely practice the exact opposite. Lecture halls with presentation slides, notes and fact heavy exams are the norm. This cannot be the structure of the education courses. preservice teachers need to be embedded in the experience of a student-centered classroom. To understand how their students will learn in those environments can be a beneficial experience to further developing PCK of preservice teachers (Lederman, Gess-Newsome, & Latz, 1994; Carrier, 2012; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2016).

The Learning Theory Revolution

The traditional teacher in the example above demonstrates no awareness of the "most substantive and revolutionary changes in learning theory in history" (Jonassen & Land, 2000). Three changes have recently revolutionized current conceptions about how people learn: (1) learning is a process of meaning making through active exploration, not knowledge transmission, that continuously occurs as learners interact with all aspects of the world; (2) learning is a process of meaning making through social interaction that requires learners to rely on feedback from others to negotiate their own understandings and personal beliefs; as such, a learning is a process of dialogue that occurs both internally within the learner and socially with others; and (3) learning is a process of meaning making strongly "influenced by communities of discourse and practice in which the learner lives…knowledge exists in individual and socially negotiating minds, but also in the discourse among individuals, the social relationships that bind them, the physical artifacts that they use and process, and the theories, models and methods they use to produce them" (Jonassen & Land, p. vi, 2000).

Activity theory is an evolving conception of learning that built on a new age of foundations of learning that leave communication theory, behaviorism, and cognitivism behind. With my proposed dissertation work, I use activity theory to frame my research in terms of designing interventions, learning products, and outcomes for investigating preservice teachers' development of PCK from an innovative, alternative notion of learning and teaching embodied in learning progressions. I will engage preservice teachers in a series of SCLEs linked in their topical emphasis on dinosaurs. These SCLEs will provide learning experiences that are active, exploratory, and student-centered. They will require preservice teachers to create scientific arguments, develop concepts, and connect science topics in life and Earth science.

Theoretical Foundations

Constructivism refers to how people create their personal understanding of an experience (Richardson, 1997). However, a solely constructivist approach to learning is not appropriate. Learning is not an individual venture, but a social journey as well that has a myriad of different influencing factors. Other students, various teachers, and instructional tools all can affect how we learn. Bandura (1977) incorporated social aspects into learning theory and the roles that behavior has on learning. Social aspects of learning go beyond the individual learner and incorporates a community of learners. Social sharing of knowledge plays an important role in learning activities (Brown & Cole, 2000). Learning is not only impacted by social settings, but it can be distributed across learners (Bell & Winn, 2000). Distributed cognition suggests knowledge is acquired and impacted by more than just an individual. Knowledge acquisition can be distributed across individuals and communities like in social cognition, but can also accounted for by artifacts and tools within a learning system.

Activity theory takes into consideration all the aforementioned learning theories. Jonassen and Rohrer-Murphy (1999) suggest that activity theory can be used to support a constructivist approach to teaching and learning. In addition to supporting a constructivist approach to learning, social aspects are necessary in an activity system. The entire system also plays a role in distributing knowledge across learners and into the objects (i.e., artifacts) they will create as part of the system. In an activity system, the learner is both socially impacted during development of artifacts and a distribution of knowledge occurs throughout the community of learners. Activity theory combines key components of constructivism, social cognitive theory and distributed cognition. It also supports the development of lessons that are found in current science classrooms, such as the BSCS 5E Instructional Model.

Beginnings of Activity Theory

Trapped in the Soviet Union until the late 1980s, activity theory provides a structure for understanding interactions between subjects, objects, and mediating artifacts (Engeström, 1987). The history of activity theory can trace its roots to Vygotsky and the successor of his research efforts, Alexei Leont'ev. Russian philosophy of behavior focused on animals for some time (i.e., Pavlov and dogs), but Leont'ev brought the foundations of behaviorism to humans. Not being able to explain everything in simple terms of doing an action for a single purpose, he theorized that maybe mediating factors played a role in human mental activity.

While activity theory refers to the action of doing, a psychological process continuously occurs as the physical activity is completed (Engeström & Miettinen, 1999). While useful, this Marxist dialectical nature of doing and cognition cannot completely explain how learning is constructed (Engeström, 1987; Jonassen, 2000). While consciousness and activity are interdependently related, more is essential for activity theory to be appropriately applied to learning environments. Activities of an individual and their consciousness are not the components of a learning environment.

Engeström Model

In 1987, Yrjö Engeström brought activity theory to its next step in evolution. His unwillingness to accept a dialectical relationship led to his suggestion of Mediating Artifacts as another interacting part of the activity system. Figure 4 shows Vygotsky's early model of activity theory. This model was insufficient for Engeström (1987) and the system expansion was vital.

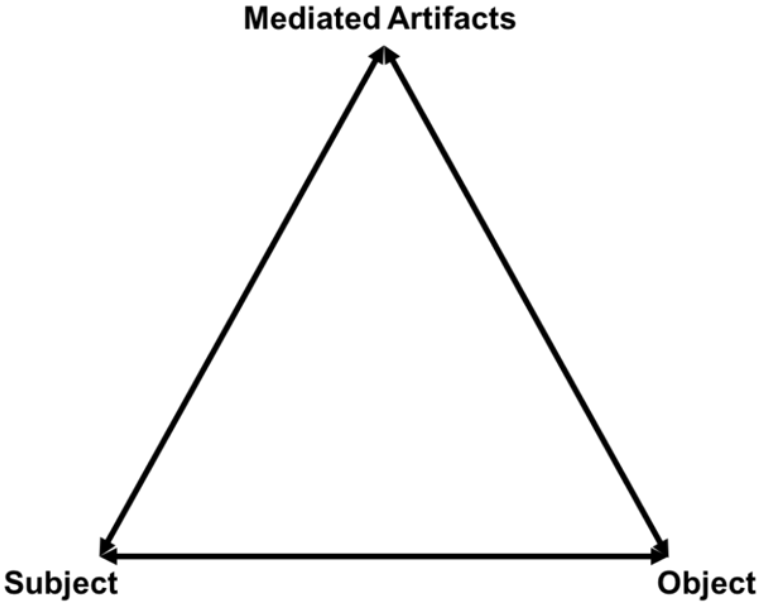

Figure 4. Vygotsky model. Subjects, Objects and Mediating Artifacts all interact with one another within an activity system. (Adapted from After *Perspectives on Activity Theory* (p. 30) by Y. Engeström, 1999, Cambridge, UK: Cambridge University Press. Copyright 1999.).

The three primary vertices of the triangle were expanded to include Tools, Rules and Division of labor. The Subject and Object became interconnected and embedded portions of the larger triangle system model. Figure 5 illustrates the new conception of activity theory proposed by Engeström.

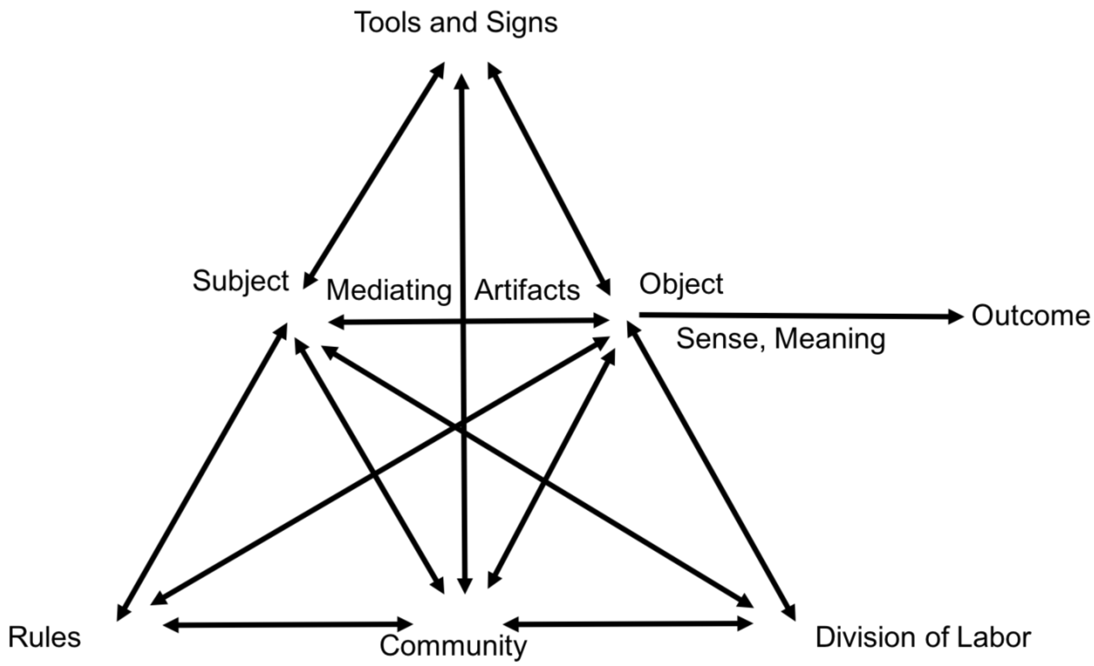

Figure 5. Engeström model. The model illustrates the relationships between the components of the human activity system developed by Engeström (Adapted from After *Perspectives on Activity Theory* (p. 30) by Y. Engeström, 1999, Cambridge, UK: Cambridge University Press. Copyright 1999.).

Six components of the new activity theory system have tangential relationships with one another (Engeström, 2001; Engeström, 2014). The Subject and Object remain operationally the same, as proposed by Vygotsky. The Subject is who is involved and the Object is the purpose. Mediated Artifacts (Figure 5) are now found on the continuum between the Subject and the Object. Signs and Tools replace the Mediating Artifacts at the apex of the triangle. Tools and Signs describe and direct how subjects will perform an activity, including curricula, hands-on materials, technology and teaching supplies. The Rules are standards established as frameworks; they include national, state, and district-level adopted learning standards and constrain the activity system. Community refers to Subjects in collaboration with one another; and Division of Labor refers to the differentiated roles of members of the Community. Situated outside of the system is the Outcome, which refers to the intention or ultimate goal of the activity.

Jonassen and Application to Student-Centered Learning

David Jonassen proposed that activity theory supported constructivist learning environments through student-mediated learning (Jonassen & Rohrer-Murphy, 1999; Jonassen, 1999). This proposition by Jonassen and his research colleagues relates the components of activity theory and principles established by Engeström (1987). SCLEs support constructivist assumptions of learning and activity theory can offer explanations to the relationships found within learning environments (Land & Hannafin, 2000; Jonassen, 2000; Land, Hannafin, & Oliver, 2012). The approach to relate activity theory to learning environments was further explained by Jonassen dividing the Engeström model into subsystems. The subsystems of the activity system include the Production, Exchange, Distribution and Consumption subsystems. This organization of subsystems simplified the Engeström model by eliminating direct relationships between Subjects and the Division of Labor and the Object and Rules. Rather, indirect relationships through Community were preferred in the Jonassen Model. This simplified version with labeled subsystems can be seen in Figure 6.

Jonassen's biggest contribution to activity theory was to simplify the Engeström model through the establishment of the subsystems. While inverse relationships existed between all points, Jonassen eliminated the direct relationships crossing the middle of the activity system triangle. This elimination makes sense, considering secondary relationships are still present but mediated through Community. For Subjects to divide labor, they must first be part of a Community; and Rules and Customs cannot independently affect the Object without Community involvement in context of a learning environment.

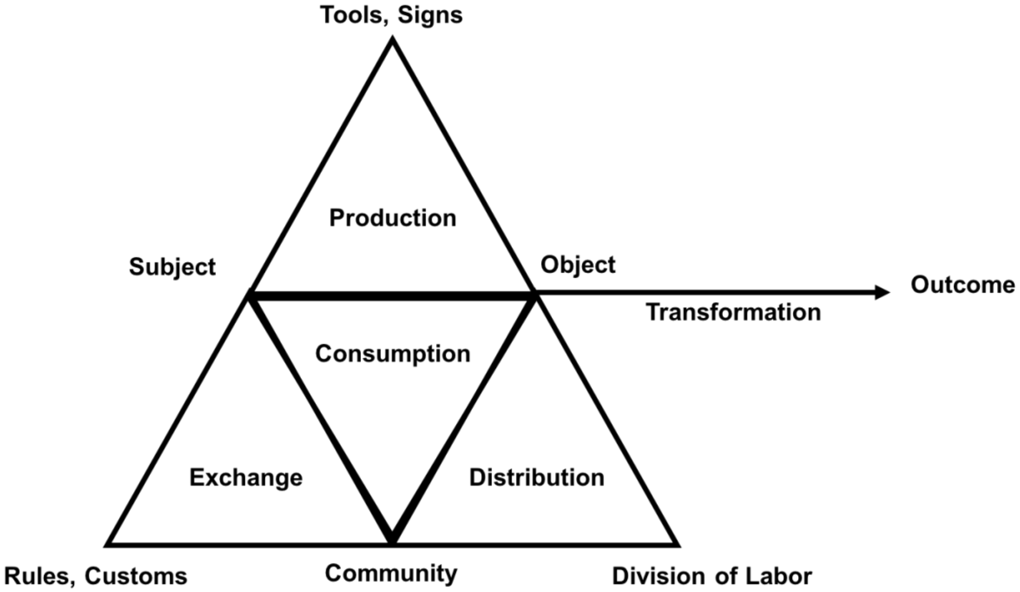

Figure 6. Jonassen model. The model highlights the subsystems of production, exchange, distribution and consumption. All components are directly or indirectly impacted. (Adapted from After *Theoretical Foundations of Learning Environments* (p. 99) by D.H. Jonassen, 2000, Mahwah, NJ: Lawrence Erlbaum Associates, Publishers. Copyright 2000.)

Production

Undergraduate education is shaped by the overall curricula and course work that institutions of higher education set for program standards. The curriculum guides and syllabi sequence learning for various fields of study. Research (Williams, Aubin, Harkin, & Cottrell, 2001; Davis et al., 2007) about premedical education have found that lecture-based coursework and computer-interfaced directed learning have no significant difference (Davis et al., 2011). A meta-analysis of research on undergraduate premedical students revealed that student-centered curriculum does not increase test scores on science content exams, but does have a positive impact on students' attitudes and clinical performance (Nandi, Chan, Chan, Chan, & Chan, 2000). This bears a resemblance to preservice teacher education. Zeichner (2010) argues that incorporating more practice and field experience to traditional university-based coursework can help aid students to develop more complex pedagogical skills. The goal of preservice teacher education should be to create best possible teachers with the most versatile practices that can be adapted to fit any student, situation or lesson. A much simpler goal, specifically for courses without a field experience component, should be to develop PCK within preservice science teachers.

Figure 7 shows the existing relationships between preservice teachers, their course curricula, their mental conceptual understandings, and how those factors help produce competent students who can develop authentic, student-centered lessons. A closer examination of the component interactions and their effect on production, within each subsystem, is useful in considering activity theory as it relates to preservice teacher education. The system above can be applied to most current models of teacher preparation; lecture-based or student-centered in nature.

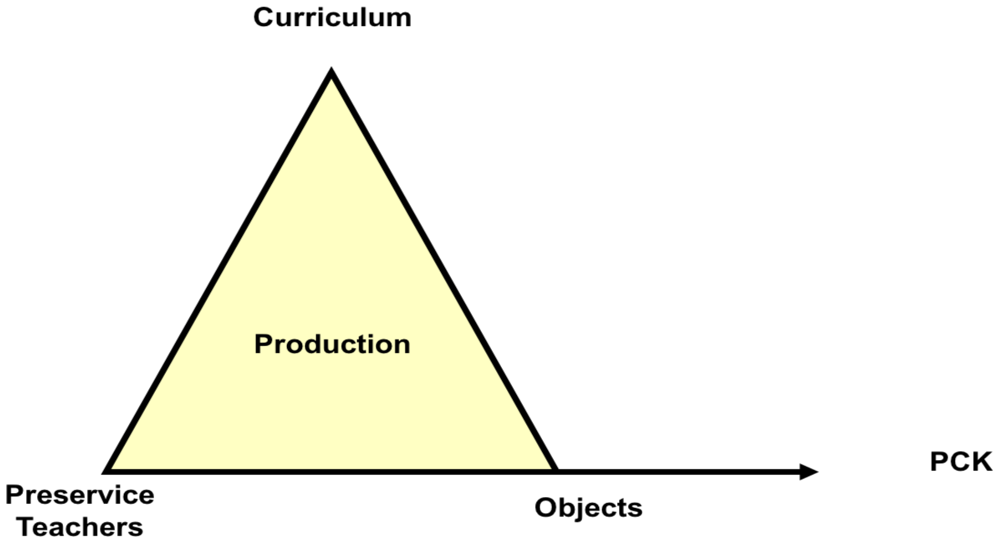

Figure 7. Production subsystem. Preservice teachers and their conceptual understandings are impacted by curriculum effecting their future lesson development. (Adapted from *Theoretical Foundations of Learning Environments* (p. 99) by D.H. Jonassen, 2000, Mahwah, NJ: Lawrence Erlbaum Associates, Publishers. Copyright 2000.)

Objects and PCK. So many times in the traditional models of instruction the Object and Outcome are the same. A test, a lab notebook, a report, and posters are all common Outcomes in the traditional model of instruction. Are these really Outcomes? What was the purpose of the test or the lab notebook? These were artifact of learning. The true Outcome of the creation of these artifacts is an increase in knowledge, skills, attitudes, and behaviors. In reformed teaching, the lab notebooks and tests are Objects for assessment, as the production of effective Objects assists in the production of the intended Outcomes of the instruction. Jonassen (2000) states, “All activity is object-oriented” (p. 100). The purpose of activity is to produce an Object that contributes to the Outcome. In a science classroom, the Outcome could be conceptual understanding, scientific practices, or the ability to use a new piece of scientific equipment (i.e., compound light microscope, spectrophotometer). Progression to the Outcome creates a transformation of the Object and the Subject. Both the Object and Subject are affected by all the other components of the activity system (i.e., Tools and Signs, Community, Rules and Customs, Division of Labor). The culmination of the activity may be represented by an Object, but the purpose was the Outcome.

A teacher may require students to create slides and analyze cells under microscope for the first time, as a part of an SCLE grounded in Activity Theory. A quiz over cells or parts of the microscope is not the Outcome. It may be an Object. Another Object would be the slide the student prepared. The Outcome of this scenario, however, is the student’s understanding of how to prepare a microscope slide and use a compound light microscope. The student may also have a high conceptual knowledge of cells due to the teacher using an Activity Theory grounded SCLE for instruction.

The Outcome for preservice teacher education is PCK. With a highly developed PCK, preservice teachers are prepared for the classroom. PCK considers both pedagogy and subject specific knowledge, thus teacher education needs to emphasize both. To promote scientific literacy, authentic science practices and inquiry principles in the classroom, it is up to teacher educators to craft instruction around the development of

PCK. If PCK is the ultimate Outcome, then all the artifacts that preservice teachers create are the Objects. Objects, such as lesson plans or concept maps, can be artifacts produced by the activity system and can be analyzed to better understand how PCK development is progressing in preservice teachers. Lesson plan analysis can uncover the potential preservice teachers have to develop authentic science lessons. Concept maps can aid in measuring how well preservice teachers subject specific knowledge is progressing. The amalgamation of lesson plans and concept maps can be critically examined to better grasp how activities that preservice teachers experience in their coursework are shaping their PCK. by the Subject (i.e., Preservice Teachers). A learner and a community create these Objects which require and produce the Outcomes. As shown in Figure 7, Preservice Teachers produce Objects (i.e., lesson plans, concept maps) that alter their PCK. This process of Objects and their direct correlation to the Outcome is part of the entire activity system and all four subsystems.

Preservice Teachers and Curriculum. Theories, philosophies, practices, content and experiences are found in curricula that guide teacher education. No model exists outlining what should be taught in the collegiate classroom. No prescribed set of rules like the *Next Generation Science Standards*, *Common Core State Standards Initiative,* or various state adopted curricula standards found available for teacher education. Textbooks, theoretical foundations and intra-departmentally developed objectives tend to drive what is taught. Autonomy is high and methods for facilitating learning are usually a choice of the individual instructor. Teaching in the K-12 sector does not offer the same affordances and freedoms that a university setting provides.

Preservice Teachers and Objects. Prior examination of PCK has emphasized the importance of the relationship between Preservice Teachers and Objects they develop. In a preservice teacher preparation course, typical Objects include learning products such as lesson plans or concept maps. These Objects represent pedagogical knowledge and content knowledge. Concept maps can be used to represent content knowledge conceptualization. Lessons plans, such as the 5E Model (Bybee, 1995; Goldston, Dantzler, Day, & Webb, 2013), require an organization of activities that promote student-centered learning and can be used to assess pedagogical strategies of preservice teachers. Lesson plans also require preservice teachers to access and use their content knowledge appropriately in the creation of authentic science lessons.

Without a rich PCK, teachers are ineffective in creating instruction that will infused both their subject specific aptitudes and their practices for facilitating a learning environment. Preservice teachers who practice reflection (Wallace & Loughran, 2012) and analyze lesson plans (Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2013), must access PCK in the process. Lessons developed by preservice teachers are weak in subject matter (i.e., science, mathematics), pedagogy or a combination of the two without a mentally unlocking PCK linked to the coursework they received as a student.

Objects and Curriculum. The curriculum of undergraduate education courses is designed to prepare students for their classrooms. This preparation can be subject specific or primarily focused on specialized pedagogy (e.g., classroom management). Regardless of the objective for a course, the curriculum of the course should support the development of preservice teachers PCK. Designing courses that support prior experiences, while minimizing misconceptions that may incorrectly affect a preservice teacher’s PCK is a tricky because each student brings in a different background knowledge to begin their PCK foundation (Hausfather, 2001). Student misconceptions from prior science courses can solidify in their minds and sometimes be near impossible to shift (Lederman & Gess-Newsome, 1999).

Reform documents support a shift from curricula that is rigid and lecture driven (Benchmarks, 1993; Designs, 2000; NRC, 2012; NGSS Leads States, 2013). A reconceptualization of teacher education programs must reflect a more student-centric model of education to model the learning environments that preservice teachers will be facilitating at their future campuses (Lederman & Gess-Newsome, 1999; Hausfather, 2001). The link between curriculum and objects (i.e., concept maps, lesson plans) supports in preservice coursework influences the abilities of students to transform conceptions into PCK.

Integration. The integration of PCK, preservice teachers and curriculum all have varying effects on one another and ultimately impact the teacher that is being prepared through coursework. Current models have teacher education with various field experiences, pedagogy-specific coursework and content related courses (Lederman & Gess-Newsome, 1999; Lyons et al., 2015). However, the teacher-directed, traditional system of disseminating information is not functional for properly preparing teachers for the next generation of students. It lacks the skills and practices that reforms over the past 20 years have been calling for and still mimics the archaic teaching practices of yesteryear. Preservice Teachers and their PCK are tied to the Curriculum that informs the Objects (i.e., lesson plans, concept maps) developed during their coursework (see Figure 7). This connection and working relationship within the production system leads to the capacity that preservice teachers will have on the final Outcome of PCK.

Exchange

The system interplay between preservice teachers, specific class activities and the NGSS all have a relationship with their eventual ability to develop authentic science lessons. Class activities should reflect the principles of student-centered learning environments (SCLEs) to promote the foundations of how to properly facilitate learning in the classroom of today (Lederman & Gess-Newsome, 1999; Land & Hannafin, 2000). The NGSS are the constraints and rules that will not only impact what preservice science teachers will teach, but should also be reflected in how they are prepared within individual science courses. Class is different from curriculum. Curriculum (Figure 7) refers to overarching objectives and sequence of coursework, while Class (Figure 8) is about the community of learners in a course and the developed activities that will guide their learning. The NGSS is an example for current K-12 standards that direct what students will learn, thus the impact of standards should be reflected in the preparation of preservice teachers and the activities they will encounter in a science education class. In Figure 8, the Exchange Subsystem shows the interconnected nature of NGSS, Class and Preservice Teachers. The relationships between each of the vertices of the system interact with one another to have a summative effect on the skills preservice teachers exchange in lesson development.

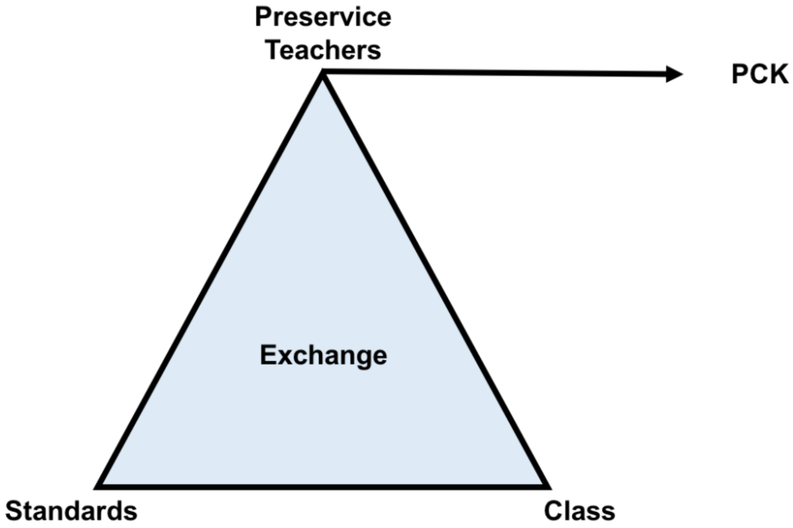

Figure 8. Exchange subsystem. Preservice Teachers and individual Dlasses are bound by Standards with respect to what they will teach and how they will learn. (Adapted from *Theoretical Foundations of Learning Environments* (p. 99) by D.H. Jonassen, 2000, Mahwah, NJ: Lawrence Erlbaum Associates, Publishers. Copyright 2000.)

Preservice Teachers and Standards. Preservice teachers need to know how to utilize the NGSS to inform their choices of how they will teach. Teaching has had a guiding curriculum in science education since the advent of curricula standards. Standards are the rules that guide what we should teach, which differs from curriculum. The rules are customs, laws or explicit regulations that shape what must be included in the curriculum (Jonassen, 2000). The *Benchmarks for Science Literacy* (1993), *National Science Education Standards* (1996), and NGSS (2013) are all governing documents that shape science curricula. With state governments having control over education policies, some states have opted to adopt national standards, while other states have developed their own sets of rules (e.g., Texas and the *Texas Essential Knowledge and Skills,* 1998; 2010).

Preservice teachers were already shaped by these rules as K-12 students. Most of the curricula experienced by current preservice teachers in K-12 classrooms was shaped by standards established in the late 1990s and early 2000s. For science, this means that the NSES or similar stated standards were the governing document during their formal education. Now as preservice teachers, they must interact with the standards on a new level. The standards they are learning to utilize (i.e., NGSS) were not what their teachers followed and reflect different values. The NGSS now champions an interacting system between core ideas, crosscutting concepts, and authentic practices in science and engineering (Bybee, 2013; NGSS Leads States, 2013). Thematic practices and crosscutting concepts span across subject specific domains of science, while the core ideas shape a timeline for when students should learn about specific topics. The interaction between preservice science teachers and NGSS shape both their future curricula choices in their classrooms and the individual lessons they will design to support the core ideas, crosscutting concepts and authentic practices.

Standards and Class. Fourteen years prior to the publishing of the NGSS, Lederman and Gess-Newsome (1999) suggested that teacher education needs to be reformed, across all courses, to reflect they methods they will use as classroom teachers. A departure from lectures and an integration of hands-on learning could be beneficial to preservice teachers, their PCK and their future lesson plans for their classrooms. A class in college should not be an individualized and isolated experience, but instead it should invoke the principles of SCLEs. Promotion of hands-on, experiential and facilitated learning are foundations of SCLEs (Land & Hannafin, 2000; Land, Hannafin, & Oliver, 2012).

The NGSS promotes the used of authentic science practices and crosscutting concepts to develop understanding in core ideas K-12 students. Planning and carrying out investigations, using models, analyzing and interpreting data, constructing explanation and designing solutions are some of the authentic practices (NGSS Leads States, 2013). These align with the characteristics of SCLEs (Jonassen & Land, 2000). If teacher education is requiring reform, then it should reflect the reforms that are happening in K-12 education. The promotion of SCLEs in a science education class allows for preservice teachers to interact with standards as currently set in schools. Preservice teacher educators must interpret the principles of new standards to frame learning activities that support the class as a community that can perform, negotiate and assume different roles to promote their own learning.

Preservice Teachers and Class. In Figure 8, Class refers to the collection of preservice teachers in a current education setting. A community of learners is developed and an exchange of ideas, understandings, and misconceptions are all found in this community structure. Preservice teachers are not just individuals, but a merger between a unique environment of multiple individuals comprising a Class. Interactions among students in the class guide learning and aid in the development of PCK. The preservice teachers are still able to have and individual identity. However, their PCK and future teaching cannot be separate from their interactions with peers. The community and structure of that community (i.e., Class) weighs how preservice teachers will build conceptual knowledge and practice authentic science pedagogy.

Integration. Traditional learning environments are highly structured, but lack the hands-on structure found in SCLEs. Teacher education classes should promote current standards to preservice teachers, so they can familiarize themselves with the rules that will govern their instruction. Classes should be designed to engage individual preservice teachers into a larger community of peers to allows an exchange of ideas. By developing classes that are founded on the principles of SCLEs, teacher educators can help prepare students who are scientifically literate in both content and practice; both as an individual and an interacting, supportive community.

Distribution

A perspective on both situated and distributed cognitions can describe the interactions between Class, Roles of Students and Objects in the Distribution Subsystem. Class situates preservice teachers into activities and structures that support Object development. The Roles of Students refer to the Division of Labor that occurs in a class. This division can be both horizontally across peers and vertically between instructor and student (Engeström & Miettinen, 1999). Different class structures and activities will call for differing divisions of labor.

Figure 9 illustrates the distribution system, placing Roles of Students, Class and Objects at the vertices of the triangle. These constituents of the Distribution System interact with one another in a tangential manner, while all components are cumulatively critical in preservice teachers' PCK development. The interactions between Objects, Class and Roles of Students are further described below.

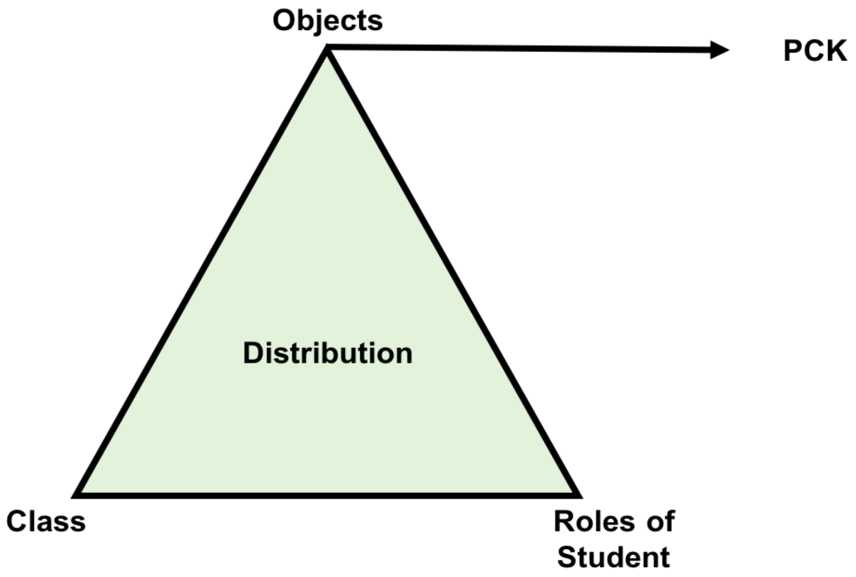

Figure 9. Distribution subsystem. Class, Roles of Student and development of Objects all have impacts on PCK maturation. (Adapted from *Theoretical Foundations of Learning Environments* (p. 99) by D.H. Jonassen, 2000, Mahwah, NJ: Lawrence Erlbaum Associates, Publishers. Copyright 2000.)

Objects and Class. Teacher education classes and other courses that preservice teachers take are outdated and apply an information processing theory approach to instruction (Lederman & Gess-Newsome, 1999). Information processing theory is the input of knowledge and processing acquired knowledge to be applicable to other situations (Wilson & Meyers, 2000). This correlates to classroom environments with a teacher-directed model and hands-off approach. Learning is more about presenting information, processing that information and committing it to memory for access in another applicable scenario. In contrast to information-processing theory is situated cognition theory. Situated cognition theory draws upon more behaviorist approaches and relies on the framework that knowledge is built and learning is contextual within a situation.

The outdated nature of college classes reflects an information processing model, as opposed to the situated cognition model supported by the NGSS. PCK development is buttressed by transforming classes focused on teacher education and shaping activities to be SCLEs (Land, Hannafin & Oliver, 2012). This constructivist approach to learning theory places students in a situation and all factors of that system effect student learning (Jonassen, Davidson, Collins, Campbell & Haag, 1995). Prior transmission models did not allow for the interaction of new knowledge and prior knowledge (Richardson, 1997); through constructing knowledge in an SCLE (i.e., concept maps), students can experiential engage in learning and build knowledge both individually and through their partnerships in the community (Novak 1991; Jonassen, 2000; Korthagen, 2010).

Class and Roles of Students. The relationship between situated and distributed cognition can be paralleled to Class and Roles of Students shown in Figure 9. Engeström (1987) emphasized the relationship between horizontal and vertical divisions of labor. The horizontal interactions are mediated by the amount of flexibility and culture of the activity (Jonassen, 2000). The ability to adapt to different situations and distribute learning across that setting applies to the roles of the students that are assumed during an SCLE. This distribution of learning relies on the situation the learners are currently facing. Not all SCLEs are created equal, thus division may be partners, a small group or an entire class. Facilitation of distributing knowledge rests on the scaffolding set in place by the instructor to ensure the SCLE incorporates both situated and distributed cognition elements.

Objects and Roles of Students. The Roles of Students have an indirect impact on how their PCK will develop through the Objects that facilitate this conceptualization. How an instructor organizes a course can determine the horizontal interactions that students will have with one another during class. PCK for individual preservice teachers will vary (Lederman, Gess-Newsome & Latz, 1994; Lederman & Gess-Newsome, 1999); if the roles of students are supported and flexible, then PCK growth opportunities can be more uniform across students (McNeill & Knight, 2013). However, if rigid constraints are set in place, the division of labor may suffer to being objective and not experiential.

Object development is dependent on the Roles of Students as part of the Distribution Subsystem. To support PCK development, the relationship between Objects and Roles of Students can provide opportunities within SCLEs for a distribution of knowledge. Historically, preservice teachers have a low PCK for science (Gess-Newsome, 1999; Gess-Newsome & Lederman, 2002). To aid in the development of PCK, roles of students can be distributed across SCLEs and facilitation by the instructor should reflect SLCE principles.

Integration. In the Distribution Subsystem, preservice teachers take on multiple roles and are situated in a specified learning environment to support situational learning and distribution of knowledge. This situated and distributed cognition supported perspective of the Distribution Subsystem can potentially lead to gains in PCK development in preservice teachers. Future Object development (i.e., lesson plans) by teachers depend on their PCK, thus the relationships of PCK to Object, Class and the Roles of Students are interrelated.

Consumption

The Consumption Subsystem (Figure 10) entails components featured in each of the other previously mentioned subsystems. Preservice Teachers were integral structures of the Production and Exchange Subsystems, Class was found in both the Exchange and Distribution Subsystems, and Objects help comprise the Production and Distribution Subsystems. These elements converge in the Consumption Subsystem. The Subjects (i.e., Preservice Teachers), Community (i.e., Class), and Object (i.e., lesson plans, concept maps) of this subsystem relate to the tenants of the other subsystems not found here in both direct and indirect manners (Jonassen, 2000).

Figure 10 clarifies the relationship between the three vertices of the Consumption Subsystem model. The consumption subsystem describes Preservice Teachers and the larger community (i.e., Class) relationship on Object development. The Class, referred by Engeström and Jonassen as Community, represents that activity cannot be accomplished alone. Preservice Teachers development of Objects (i.e., lesson plans, concept maps) require a Community involvement. Energy from the Preservice Teachers and Class are both consumed in the development of Objects. This Object development then acts upon the growth preservice teachers' PCK.

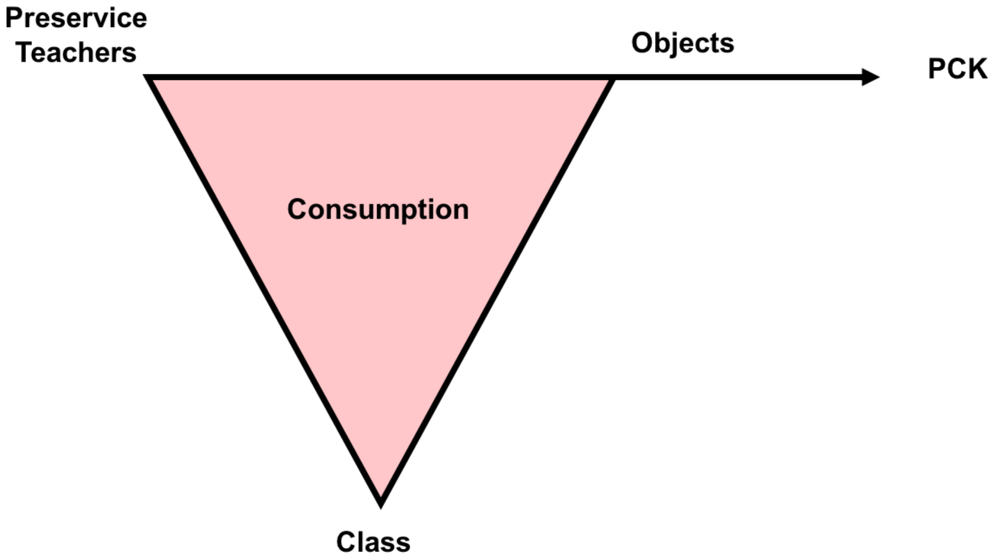

Figure 10. Consumption subsystem. Preservice Teachers and Class consume energy through activity in development of Objects on PCK growth. (Adapted from *Theoretical Foundations of Learning Environments* (p. 99) by D.H. Jonassen, 2000, Mahwah, NJ: Lawrence Erlbaum Associates, Publishers. Copyright 2000.)

Lyons Adaptable Model

Activity theory provides a framework with its application to learning environments (Jonassen, 2000) and recommendations for more student-centered learning in preservice teacher education (Gess-Newsome & Lederman, 1993; Gess-Newsome, 1999; Van Driel, Jong, & Verloop, 2002; Carrier, 2012; McNeill & Knight, 2013). The Lyons Adaptable Model proposes a practical adaptation to Engeström’s theoretical framework of activity theory for structuring preservice teachers’ education around SCLEs to support the tenets established by activity theory. This adapted framework could also be adapted to K-12 learning by changing the subject, preservice teachers, to grade appropriate learners.

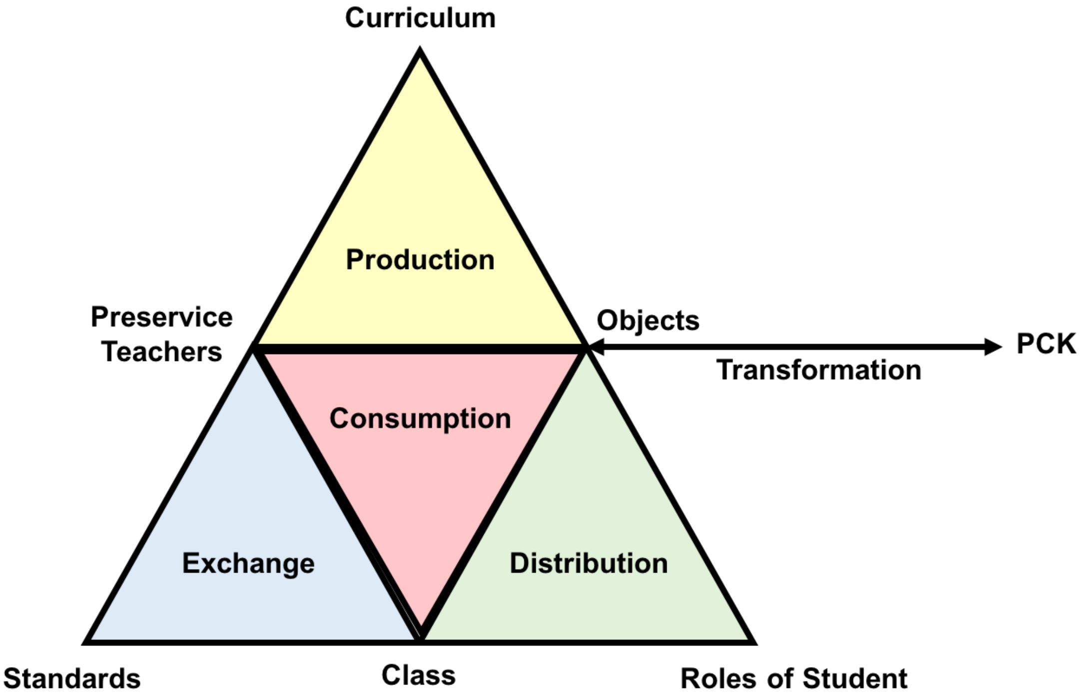

Figure 11. Lyons adaptable model. The model builds upon Jonassen's tenants of Activity Theory with relation to teacher education, specifically science education in this example. (Adapted from *Theoretical Foundations of Learning Environments* (p. 99) by D.H. Jonassen, 2000, Mahwah, NJ: Lawrence Erlbaum Associates, Publishers. Copyright 2000.)

Figure 11 shows the adapted framework based on Engeström's theoretical framework with appropriate terms for preservice teacher educators. This foundation practically replaces Engeström's with specific terminologies that relate to a specific subject, preservice science teachers. The outcome of the model is PCK, as it is a driving force for teacher development.

The Objects of lesson development and conceptual knowledge refers to the applied knowledge of preservice teachers gained through the activity system that impacts their ability to transform PCK into authentic, integrated, and student-centered lessons.

Curricula are the Tool and Signs that are impacting the activity system for preservice teacher education, as it drives what and how the preservice teachers will learn. State or national standards can be placed for the Rules as they govern what the preservice teachers learned as a K-12 student and what they will teach in the future. For the purposes of this study, NGSS was chosen to represent the science standards establishing the rules for the system. The Community of Engeström's model is paralleled to specific teacher education courses that preservice teachers would be enrolled during the interaction with the system. Finally, the Role of Students refers to the Division of Learners and is directly impacted by the individual students.

Adaptability of the Lyons Adaptable Model for activity theory allows it to be used for any preservice teacher preparation concentration area that support the use of SCLEs or within a K-12 setting. The NGSS would be substituted for standards in other subjects adapt the model to mathematics, social studies or language arts disciplines in preservice teacher education. This would allow adoption at both national and state standards level. To modify this model for appropriate use and support of student-centered learning in a K-12 setting, the rules would have to be aligned to the subject-specific course and the subjects would change from preservice teachers to K-12 students. The outcome would no longer be PCK but content knowledge of K-12 learners.

Adaptations such as the one I propose represent next evolutionary step in activity theory. Leont'ev built on Vygotsky's foundations to be improved upon by various other philosophers (i.e., Kant, Hegel, Marx) (Kuutti, 1996). Engeström drastically took activity theory to a new paradigm. No longer was it a simple interaction of an individual but communities and the functions within those communities impacted the outcome of the activity system. Jonassen simplified some aspects of Engeström’s model, while establishing the conception of subsystems. My proposed adaptation uses Jonassen’s model and applies it directly to SCLEs. Jonassen and Land (2000) allude to the relation and Jonassen (2000) makes a case for it in technology infused learning environments. Figure 11 represents a more general and adaptable structure of activity theory for SCLEs. This system can be applied to single lessons, larger units of instruction and learning progressions.

Learning Progressions

Old curricula based on textbooks offered an incomplete and nonintegrated approach to concepts that included too many unnecessary details (Fortus & Krajick, 2011). Curriculum coherence is the “alignment of specified ideas, the depth at which the ideas are studied, and the sequencing of topics within each grade and across grades” (Fortus & Krajick, 2011, p.783). Learning progressions (LPs) offer the frameworks for aligning instruction across grades, integrating concepts and assessment based on more than just right or wrong answer choices. In *Taking Science to School,* the National Research Council (NRC) provided an operational definition for LPs in 2007.

> Learning progressions in science are empirically grounded and testable hypothesis about how students’ understanding of, and ability to use, core scientific concepts and explanations and related scientific practices grow and become more sophisticated over time, with the appropriate instruction. (p.8)

This definition sums up the purpose of LPs and LP research. Researchers are trying to establish LPs that will progress conceptual understanding through integrated and student-centered instruction.

Foundations of Learning Progressions

Curricula guideline documents are most likely the primitive ancestors of LPs. LPs, sometime referred to learning trajectories in mathematics education, have evolved over time and offer a more sophisticated way of organizing learning activities for the promotion of high conceptual understanding (Duschl, Maeng, & Sezen, 2011). The *Benchmarks for Science Literacy* (AAAS, 1993) paved the way for modern curricula reform. This was a companion text to *Science for All Americans* (SFAA) and it explains how students' science literacy should progress over time, much like a LP. This was an attempt at reforming how science was taught and was one of the initial widespread efforts to make science learning more authentic and student-focused. A supporting publication to *Benchmarks* was the *Designs for Science Literacy* (AAAS, 2000). The *Designs* aimed to guide curriculum design so that learning was aligned from Kindergarten through high school. This task was approached as a design problem that will help produce more aligned curricula with similar learning goals, while maintaining a diversity of how the content is delivered. It attempted to fix cumbersome requirements that were thought to be needed for an adequate curriculum and redefine the meaning of what would be effective for the students of the 21st century. Following the publication of *Designs* was the two installments of the *Atlas of Science Literacy*. Two volumes were published in 2001 and 2007 (AAAS, 2001; AAAS, 2007). These included strand maps that banded grades from Kindergarten to second grade, third to fifth grade, middle school and high school. The strand maps were thematic and provided connections between standards and conceptions of students (Black, Wilson, & Yao, 2011). While strand maps organized concepts across grade bands over thematic topics, actual teaching practices were not suggested. Strand maps may be the *Archaeopteryx* or *Australopithecus* fossil for modern-day learning progressions.

On a national level, between the publications of *Benchmarks* (AAAS, 1993) and *Designs* (AAAS, 2000), the National Science Education Standards (NSES) were formed in 1996 (NRC, 1996). These standards offered a nationwide science curriculum that promoted student-centered learning and conceptual understandings. The successor of the NSES were the NGSS in 2013. Science and engineering practices are at the heart of the NGSS with the promotion of student-centered learning through inquiry and investigations to develop core conceptual understanding of main topics and link them to prior knowledge. The disciplinary core ideas (DCIs) are vast enough to encompass multiple topics across grade levels and subject areas, thus creating a more integrated curriculum. By this, the NGSS are attempting to create deeper level of science understanding, or science literacy, in the fields of life, physical and earth sciences. Standards are organized by grade for traditional elementary ages (K-2; 3-5) and then grouped in bands of middle school (6-8) and high school (9-12), rather than mandating at what age or grade these concepts are taught. This reflects the grade banding found in the two volumes of *Atlas*.

LPs are called for to support current NGSS but strand maps are not provided and integration can imprecise. This leaves the development of LPs up to science education researchers. The following sections will explain the components of learning progressions, current research and a potential theme for developing an LP for life and earth science topics.

Clear understandings of what students should know and constructing this in a map (strand map) provides a clearer focus for implementation of the learning progression. One thing Krajcik suggests is that construct maps (strand maps) offer more when content ideas develop across grade-bands or time, but to also include how the nodes of the maps show how ideas are linked (*add words on the strand maps arrows like on concept maps, blend the two "Concept strand map")*. Krajcik's second suggestion is that construct maps (strand maps) and learning progressions need to be thought of from a developmental perspective, or evolution LP mindset. One of Krajcik's final points is that although LPs are time consuming with development, they offer a way to "push student thinking forward on the core ideas of science."

Components of Learning Progressions

LPs should clarify how to align standards (i.e., NGSS) to instruction (Corcoran, Mosher, & Rogat, 2009). This beneficial tool can give teachers the ability to assess students on development of conceptual understanding over time (Mosher, 2011; Wiser, Smith, & Doubler, 2012). There are five essential components to LPs. They must target clear end points defined by a central theme. LPs need to identify scopes of conceptual understanding of core ideas and practices. Operationally defined level of conceptual understanding (i.e., adequate, intermediate, advanced) need to accompany a LP. These operational definitions need to be applied to specific learning activities within the LP. Finally, assessments need to be developed that measure student understanding of key concepts. How LPs are structured, defined, sequenced and validated is still under debate (Duschl, Maeng, & Sezen, 2011; Krajick, 2011).

LPs offer a way of sequencing learning so that foundations are built early and prior knowledge is readily accessed (Duncan & Hmelo-Silver, 2009). Two main types exist, validation and evolutionary LPs (Duschl, Maeng, & Sezen, 2011). Evolutionary LPs develop from a base-level of knowledge and progress over time. Evolutionary LPs have explored celestial motion (Plummer & Krajick, 2010), microevolution (Metz, 2011), matter (Smith, Wiser, & Carraher, 2010; Steven, Delgado, & Krajcik, 2010) and the formation of the solar system (Plummer et al., 2015). Validation LPs are less preferred because they do not meet the suggestion of operational defined phases of learning in the intermediate phases of the progression (Corcoran, Mosher, & Rogat, 2009; Duncan, Rogat, & Yarden, 2009; Duschl, Maeng, & Sezen, 2011; Rogat, 2011). LPs are potential avenues to incorporate the principles of student-centered learning (Corcoran, Mosher, & Rogat, 2009; NRC, 2012). Aligned and thematic SCLEs incorporated as the basis of LPs learning activities could provide necessary scaffolding and integration across grade bands with a focus on both core ideas, crosscutting concepts and science practices (Gotwals & Songer, 2013; NGSS Leads States, 2013).

With research of LPs being rather new, many concerns still exist. Accepted guiding frameworks are not in agreement amongst researchers (Duschl, Maeng, &

Sezen, 2011). Another area of contention is that LPs can strengthen immature conceptions and limit instructional methods if not properly designed (Shavelson & Kurpius, 2012). PCK of teachers is also a concern with regards to LPs and them functioning in a proper manner (Krajick, 2011). Krajick (2011) states:

> Although some teachers will have the pedagogical content knowledge to develop particular tasks to move students forward, learning progressions need to provide a set of ideas that teachers can modify to fit the needs of their classroom situations. (p.157)

Duschl, Maeng, and Sezen (2011) recommend that "LPs in actual teaching and planning is understudied" (p.169). Research studies on the incorporation of LPs into preservice teacher education and in-service teacher training are recommended. Bransford, Brown, and Cocking (2000) declares effective teacher education involves "learning activities that are similar to ones that they will use with their students" (p.204).

Student Interests

Thematic developments of LPs are one of the main components when developing a LP. Having a topic of high student interest can help shape the experience for the students and engage them in learning. Students' interest in science declines with age, but a more positive attitude is reflected when involved in hands-on activities that are investigation based (Kerr & Murphy, 2011). Researchers need to examine student interests within a sequence of activity with the design of curricula being a focus, rather than just the problem or personal connection to the activity (Swarat, Ortony, & Revelle, 2012). Topics of high interest could be incorporated into the development of LPs to mitigate this decline of students' interest in science.

In one study, the number one science interest of students entering Kindergarten was dinosaurs (Johnson, Alexander, Spencer, Leibham, & Neitzel, 2004). However, topics like dinosaurs are not explicitly stated in curricula standards (NRC, 1996; TEKS, 2010; NGSS Leads States, 2013). It is not uncommon for a specific topic to be absent. Core ideas, crosscutting concepts, and science practices are the focus of current curriculum guides (i.e., NGSS); however, attaching a student interest, such as dinosaurs, to a LP allows for students to connect to concepts embedded within and associated with that interest. A LP on dinosaurs could integrate principles of life and earth science, while SCLEs within the LP can support authentic scientific skills students are expected to develop in K-12 education.

Conclusion

Increasing PCK in preservice teachers is a major goal in teacher education. Specifically in science, teachers need to have a high level of understanding of both science concepts and skills. Teacher education needs to also imitate the methods being used in field experiences and do away with teacher-directed lectures (Gess-Newsome & Lederman, 1993). Incorporating SCLEs into preservice science teacher education would help incorporate science practices with core subject-specific concepts (Land, Hannafin, & Oliver, 2012; Bybee, 2014). Hmelo, Holton, and Koldner (2000) state "In life science…there is often an emphasis on understanding isolated concepts without introducing learners to the interrelations among various levels of systems" (p. 250). LPs offer a pathway of organizing these SCLEs in a thematic manner (e.g., dinosaurs), integrating multiple topics of science (i.e., evolution, geology, rock layers, traits, habitats, organisms, ecology) and researchers suggest that LPs have not been studied with preservice teachers (Duschl, Maeng, & Sezen, 2011).

According to HPL, "many learning opportunities for teachers fall short when viewed from the perspectives of being learner, knowledge, assessment, and community centered" (p.204). Successful teacher development includes activities that are "extended over time" and encourage discourse amongst a group of learners (Bransford, Brown, & Cocking, 2000). By incorporating a thematic unit (e.g., a hypothetical learning progression themed on dinosaurs for K-9 life and Earth science) in science teacher education, preservice teachers can remain engaged in their learning, mature their PCK across grade bands they could potentially teach, integrate knowledge between science domains and cultivate science practices they will need as a future science teacher. In *How People Learn*, Bransford, Brown, and Cocking (2000) state that "environments that are learner-centered attempt to build on the strengths, interests, and needs of the learners" (p.192).

We need to be able to push our preservice teachers through rigorous but meaningful learning activities that help develop highly functioning PCK. With more advanced PCK, preservice teachers would then be able to develop authentic, integrated, and student-centered lessons for their future classrooms.

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