A Case Study of Secondary Teachers Facilitating a Historical Problem-Based Learning Instructional Unit

John L. Pecore

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This dissertation, A CASE STUDY OF SECONDARY TEACHERS FACILITATING A HISTORICAL PROBLEM-BASED LEARNING INSTRUCTIONAL UNIT, by JOHN LEE PECORE, was prepared under the direction of the candidate’s Dissertation Advisory Committee. It was accepted by the committee members in partial fulfillment of the requirements for the degree Doctor of Philosophy in the College of Education, Georgia State University.

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Current curriculum trends promote inquiry-based student-centered strategies as a way to foster critical thinking and learning. Problem-based learning (PBL), a type of inquiry focusing on an issue or “problem,” is an instructional approach taught on the basis that science reform efforts increase scientific literacy. PBL is a constructivist approach to learning real life problems where understanding is a function of content, context, experiences, and learner goals; historical PBL situates the lesson in a historical context and provides opportunities for teaching NOS concepts. While much research exists on the benefits of historical PBL to student learning in general, more research is warranted on how teachers implement PBL in the secondary science curriculum.

The purpose of this study was to examine the classroom-learning environment of four science teachers implementing a historical PBL instructional unit to identify the teachers’ understandings, successes and obstacles. By identifying teachers’ possible achievements and barriers with implementing a constructivist philosophy when executing historical PBL, educators and curriculum designers may improve alignment of the learning environment to constructivist principles. A qualitative interpretive case study guided this research study. The four participants of this study were purposefully and conveniently selected from biology teachers with at least three years of teaching experience, degrees in education, State Licensure, and completion of a PBL workshop.
Data collection consisted of pre and post questionnaires, structured interviews, a card sort activity in which participants categorized instructional outcomes, and participant observations.

Results indicated that the four teachers assimilated reform-based constructivist practices to fit within their preexisting routines and highlighted the importance of incorporating teachers’ current systems into reform-based teacher instruction. While participating teachers addressed a few NOS tenets, emphasizing the full range of possible NOS objectives included in historical PBL is warranted. This study also revealed the importance of creating a collaborative classroom culture and building positive student-teacher relationships when implementing PBL instruction. The four teachers agreed that the historical PBL instructional unit provided a context for learning state standards, and they positively viewed their experiences teaching the lesson. Thus findings from this study suggest that teaching science in a historical context using PBL can be effective.
A CASE STUDY OF SECONDARY TEACHERS FACILITATING A HISTORICAL PROBLEM-BASED LEARNING INSTRUCTIONAL UNIT
by
John L. Pecore

A Dissertation

Presented in Partial Fulfillment of Requirements for the Degree of Doctor of Philosophy in Teaching and Learning in the Department of Middle-Secondary Education and Instructional Technology in the College of Education Georgia State University

Atlanta, GA 2009
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Come to the edge,
it’s too high!
Come to the edge,
we might fall!
Come to the edge,
and they came,
and he pushed them,
and they flew.

-Apollinaire

This dissertation is dedicated to those that called me, pushed me, and flew with me.

With support and confidence of my parents, John and Shirley Pecore, family and friends, I answered the call to begin my journey toward furthering my education in teaching and learning. I would like to first thank Dr. Nydia Hanna for encouraging and mentoring me every step of the way.

This dissertation would not have been possible without the assistance of those who pushed me, mostly my professors and especially my committee members for their caring dedication. Much gratitude is offered to my major advisor, Dr. Lisa Martin-Hansen, for her expert guidance and my co-chair, Dr. Chara Bohan, for her comically abrasive critique. Appreciation is extended to Dr. Dennis Thompson for his thoughtful comments and to Dr. Mike Dias for his detailed feedback. Special thanks to my WFU students for their assistance with gathering lesson resources, colleagues at WFU for their support and the four CERTL graduates (Beth, Dana, Emma, and Mark) who participated in this study.

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Dedicated in loving memory of my grandparents, Ernest and Helen Pecore, Dell and Dorthy Girard who have always been with me in spirit as I completed my flight.
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CHAPTER 1
INTRODUCTION

Background

The current science education reform movement endorses a change in instruction by describing a curriculum that focuses on meaningful student learning, depth over breadth of understanding, and learning in context (AAAS, 1993; AAAS, 1989; NRC, 1996). According to Science for All Americans: Project 2061 (AAAS, 1989), the primary objective of science reform is to promote science literacy by providing “recommendations on what understandings and ways of thinking are essential for all citizens in a world shaped by science and technology” (p. xiii). More explicit recommendations are found in The National Science Education Standards (NRC, 1996) where science literacy is defined in terms of learning outcomes categorized as science as inquiry; subject matter for physical, life, and earth/space science; science and technology; science in personal and social perspectives; and history and nature of science. Applying history to teaching science assists with all five facets of scientific literacy. Through teaching historical case studies, students can view science as inquiry and view the scientist’s investigation in context of the historical time. Students explore and discuss science concepts throughout the case. As the story unfolds, students recognize how technology influences science and the interactions
between science and society. By making a historical case the context of teaching, students develop an understanding of the scientific enterprise in different historical and cultural perspectives.

Science reform advocates also promote inquiry-based instruction that entails student-centered constructivist learning environments. The roots of constructivist learning date back to John Dewey and the notion that children learn through experiences with real-world problems and during discussions with others (Crawford, 2000; Dewey, 1915/1991). Constructivist learning provides theoretical support for creating reform-based classroom environments where students revise their understandings by interacting with the environment and thinking critically (Crawford, 2000; Driver, Asoko, Leach, Mortimer, & Scott, 1994). According to Savery & Duff (1995), PBL provides an instructional strategy that aligns with constructivist principles of personal relevance, problem ownership, cognitively demanding, complex, solving problems, value and challenge thinking, testing ideas, and reflective thought.

Historical case studies combined with PBL can be used to guide instruction such that learning outcomes from each of the categories of the national standards can be incorporated throughout a unit of instruction. A PBL approach to learning is gaining popularity in school curriculum throughout the United States as a way of increasing student gains in cognition, development of skills, independent learning, cooperation, and motivation (Chiappetta & Koballa, 2006; Smith, 1995; Sonmez & Lee, 2003; Weller & Karp-Boss, 2007). However, teachers often experience challenges when attempting to facilitate PBL (Barron, Schwartz, Vye, et. al., 1998; Jones, 1996; Sonmez & Lee, 2004). Thomas (2000) and Hmelo-Silver (2004) both comment on the need for PBL research in
K-12 education. Hmelo-Silver recommends conducting empirical studies that will inform educators about adapting PBL into the secondary curriculum. More specifically, she suggests investigating how teachers adapt PBL instruction in the classroom.

The National Science Teachers Association (NSTA), literature published by NSTA Press, and National Science Foundation (NSF) funded professional development opportunities provide a plethora of resources to persuade educators to implement reform-based practices. While resources are available to assist teachers to modify their teaching strategies, sufficient instruction in how to facilitate these types of environments and in understanding constructivist philosophies may be warranted.

Each year for the past 12 years, groups of teachers have participated in a PBL workshop presented by the Center for Excellence in Research, Teaching, and Learning (CERTL), which operates as an extension program of a major university in the southeastern United States. The goal of the workshop is to train teachers in the PBL method so they may facilitate learning that connects better with students. During the one-week workshop, instruction focuses mostly on teachers implementing and writing PBL cases aligned to state content standards. Two important components of implementing PBL are facilitation and design. Workshop facilitators inform teachers of some rules as well as common recommendations for good classroom management techniques when facilitating PBL. Facilitators also explain that a good design is dependent upon the quality of the problem to produce student-generated questions that match state standards.

During the professional development workshop, teachers learn about PBL through participating in several PBL activities. The first of five scenarios from the workshop that teachers experience is as follows:
As an educator in your current position you have been asked to attend this seminar in problem-based learning. It is intended that you become expert enough in this topic to communicate its philosophies and underlying principles to your colleagues. As a peer consultant in PBL you may have to address the questions and concerns of other educators (CERTL, 2008).

This initial scenario illustrates how the workshop presenters modeled for the participants of this study how to conduct PBL lessons.

In the summer of 2008, twenty-seven teachers representing seven schools from around the district sat in small groups of four to five per table. Each group was first asked to identify their own concerns regarding the above problem by creating a T-chart with a list of “need to know” items or learning issues on one side of the T and an action plan for pursuing these learning issues with possible resources on the other side of the T. During the remainder of the week as teachers observed, experienced, and wrote PBL lessons, whole-group discussions provided a means for addressing the teachers’ learning issues.

Another activity teachers experienced during the week was observing a veteran PBL facilitator perform a PBL lesson with high school students. After observing PBL in action, workshop facilitators addressed concerns regarding potential challenges teachers might encounter when implementing PBL curriculum. The discussion revealed that observing PBL in action provides teachers with confidence to execute a constructivist strategy. Teacher concerns included the following: 1) directing students without giving information, 2) asking the right questions, and 3) using the right resources. In their small groups, teachers developed a one-hour PBL lesson and subsequently taught their lesson to high school students. The follow-up discussion had teachers directing their concerns to more classroom management issues such as: 1) how to teach students to work in groups, 2) wait time, 3) assigning roles, and 4) teaching procedures. The evolvement of concerns
from general to specific obstacles shows how teachers were focusing on classroom facilitation of PBL. The professional development workshop addressed many issues for implementing reform-based practices important for secondary science teachers. However, what was not discussed during the course could be more important than what was considered. Issues of importance omitted from the workshop include details of constructivist learning principles or alignment of PBL cases to non-subject specific content standards, or more specifically, history and nature of science standards.

The reason for emphasizing history and nature of science in this study is in part due to the reform efforts advocated by publications such as *Science for All Americans: Project 2061* and the *National Science Education Standards*. These reform documents place a more prominent emphasis on the history and nature of science in the science curriculum. The science curricula (BSCS, CBA, CHEM, ESCP, HPP, PSSC, etc.) developed during the era preceding reform publications encouraged the Bruner-inspired inquiry teaching method (Matthews, 1989) where inquiry is defined as an active learning strategy centered on student’s questions. Bruner viewed learning as an active process where instruction provides experiences and contexts enabling students to generate new explanations and increase the manipulation of new information (Bruner 1960; Bruner 1966; Bruner, 1973). With the exception of the Harvard Physics Project (HPP), what was of a minor consideration in the science curricula was learning about the history, philosophy, and social context of science. Matthews suggested that historians and philosophers of science have an important role to play in science education noting that “their collaboration with science educators has been too infrequent” (Matthews, 1989, p. 5). According to Hodson (1988) the history and philosophy of science might assist with
the “major shift of emphasis away from teaching of science as a body of established knowledge toward science as a human activity with increasing emphasis on experience of the processes and procedures of science” (p. 19) as was the case with HPP curriculum.

Statement of the Problem

To implement student-centered instruction as intended by reform-based curriculum such as PBL, teachers must effectively facilitate the classroom learning environment, which entails overcoming possible pedagogical obstacles, and identify successes in order to maximize learning using inquiry-based instruction. National reform movements advanced by professional organizations (AAAS, 1993; NRC, 1996), and international assessment endeavors (Stigler & Hiebert, 1999) recommend that educators reevaluate their approach to teaching and learning science with respect to reform recommendations as a means of increasing scientific literacy for all Americans.

Constructivist learning theorists such as Vygotsky (1978) and Piaget (Wadsworth, 1996) are the impetus for curricular and instructional changes toward more inquiry-based strategies. Following constructivist recommendations as defined in national and state standards, school districts are implementing curriculum materials aligned to reform-based inquiry practices such as PBL.

A more active learning approach is being adopted by school systems with the goal of improving student critical thinking skills. PBL is one method that has gained popularity in the county where this study took place and the surrounding counties for its potential to increase student gains in cognition. Despite efforts to provide teachers with training in designing and facilitating PBL through programs such as the one CERTL
offers, teachers continue to experience challenges when attempting to facilitate PBL (Barron et. al., 1998; Jones, 1996; Sonmez & Lee, 2004). According to both Thomas (2000) and Hmelo-Silver (2004), there is a gap in the secondary education research with respect to advising teachers in facilitating PBL. Hmelo-Silver (2004) also suggests more research focusing on investigating how teachers adapt PBL instruction in the curriculum.

PBL has the potential to provide a better understanding of the history and nature of science curriculum standards. Fowler (2000) and Duschl (2000) found using history in science teaching with post-secondary students to be effective in terms of enhancing science learning. If applying history to teaching science is to assist with scientific literacy in the history and nature of science, Allchin (2000) contends that the historical context requires a prominent place in the lesson. However, the practice of using history to teach science is not common in K-12 education (Murphy & Biggs, 2005).

*Science for All Americans* (AAAS, 1989) declares the following:

> There are two principle reasons for including some knowledge of history among the recommendations. One is that generalizations about how the scientific enterprise operates would be empty without concrete examples. A second reason is that some episodes in the history of the scientific endeavor are of surpassing significance to our cultural heritage (Matthews, 1992, p. 237).

Matthews (1992) maintains that an intent of science reform is for history and philosophy of science to be integrated and discussed within science courses. Furthermore, he envisions students’ learning to appreciate intellectual issues at stake, questions being asked, and less about answers and more about evidence that supports answers. One issue that Matthews (1992) raised is the need to revise curricular plans to realize AAAS recommendations into classrooms.
Purpose of the Study

The purpose of this study was to explore teachers’ perceptions and facilitation of their classroom learning environments during historical PBL science instruction. Teachers of PBL curriculum devise learning environments that are consistent with their pedagogical understanding of constructivist learning theory (Savery & Duffy, 1995). By identifying the teachers’ operational understanding of constructivism, a foundation was built to interpret how teachers’ implementation of PBL aligned with constructivist principles. This study also identified teachers’ perceived successes and obstacles that were encountered in the educational environment and culture. While perceptions varied from teacher to teacher, looking at the impediments and possibilities that arose for individual teachers informed possible barriers and achievements teachers encounter while facilitating historical PBL instructional units.

Research Questions

This study focused on secondary science educators’ facilitation of PBL as they taught science concepts from a historical perspective. Teachers are responsible for developing learning environments that are consistent with professional standards, which involve teaching science as inquiry using student-centered activities (NRC, 1996). Professional standards for teaching science were developed by teams of educators and scientists with the goal of improving science instruction and increasing scientific literacy. Achieving this goal depends heavily on teachers facilitation of the learning environments developed for PBL instructional units. Additionally, teachers may encounter pedagogical obstacles or events that interfere with or hinder learning, limitations or events that restrict
or weaken learning, and successes or events of desired achievement within the learning environment as they facilitate PBL instructional units. This qualitative study focused on two research questions.

Question One: How do teachers’ PBL instructional practices align with constructivist principles? Based on the assumption that successful implementation of PBL instruction relies on teachers’ alignment to constructivist learning principles (Savery & Duffy, 1995), research question one investigated the teachers’ instructional learning environment. Constructivist principles encompass real-world problem-solving, student-ownership, inquiry, and reflection.

Question Two: How do teachers facilitate historical PBL instruction in science classrooms? The second question addressed two sub questions. Why might teachers experience pedagogical successes, obstacles, and limitations while facilitating historical PBL lessons? What is the possibility of teaching history and nature of science through PBL instruction? These research questions identified the perceived barriers and accomplishments that teachers encountered while facilitating a historical PBL instructional unit in science classrooms.

Theoretical framework

The theoretical framework for this study draws upon ideas from PBL and constructivist learning theory. PBL is a type of inquiry pedagogy where students investigate science content and social implications involved in a real-world problem. The use of problem-based learning supports the social interactions (Barows & Kelson, 1995) that are necessary to motivate and engage learners in the science classroom. The
strategies for choosing a historical aspect within PBL in science makes science and history of science personally relevant, allows for students to explore and understand the uncertainty of science, encourages share control of the learning environment, affords critical voice of students' learning activities, and promotes student negotiation of ideas. The central ideas of problem-based learning are couched within constructivist learning theory as students are actively considering their and others' ideas, as they explore and refine their understandings of scientific and historical content (Savery & Duff, 1995).

The National Science Education Standards (NSES) stress the importance of incorporating scientific inquiry into the curriculum, purposefully listing this standard first in each of the specified content areas (NRC, 1996). Constructivism aligns well with inquiry pedagogy as it places emphasis on the learner’s ownership of ideas and a personal interpretation of knowledge. In theory, students become less dependent on teachers and texts for answers, and more reliant on the content knowledge they acquired through personal research, their judgment and common sense. A historical PBL is a pedagogical strategy empowering students through a constructivist approach to learning about real life historical problems, where understanding is a function of content, context, experiences, and learner goals.

Despite an attempt to focus science instruction on the process of inquiry rather than rote memory of scientific facts, the assessments associated with No Child Left Behind (NCLB) appear to have pushed teaching back toward a more “positivist” or “objectivist” perspective. An objectivist epistemology, grounded by the epistemology of classical scientific realism, is philosophically founded on the assumption that truth can be represented by observable phenomena and scientifically verifiable facts. Objectivists
claim that there is an external world that is knowable. According to objectivists, knowledge is discovered, proved, and accepted by society; therefore, learning often consists of transmitting information to students through generally passive instructional means (Dana & Davis, 1993). Behaviorist practices that reduce teaching to the transmission of information to students, learning for the acquisition of information, and understanding to the degree to which information is effectively transmitted are emphasized within the objectivist framework (Richardson, 1996).

Objectivism provides a passive means for knowing and a reliable avenue to the truth, which results in a “black and white” world of objective knowable realities. While objectivism is an attractive framework due to people’s natural tendency to rely on beliefs that are fixed by some form of authority, Dewey (1916) contended that "such actions function to relieve people from the trouble of thinking and the responsibility of directing their activity by thought" (p. 267). The result of promoting an external imposition negatively impacts students by potentially limiting their intellectual and moral development. Within a strict objectivist framework, the emphasis is placed on preparing students for study to work within a discipline by acquiring academic content knowledge and not on creating constructivist learning opportunities for students.

Constructivism is the view that knowledge is individually constructed, socially developed, and transmitted by the interaction between human beings and the world they inhabit (Crotty, 1998). For von Glassersfeld (1993), radical constructivists view knowledge as actively and personally constructed by cognizant people through an adaptive process that organizes individual world experiences. The concept of truth is replaced with viability and refers only to the experiential field. Constructivists do not
deny, as claimed by realists, the existence of the real world; they deny the possibility of discovering objective knowledge of the real world. Thus, constructivist researchers are not interested in seeking truth, but rather finding meaning through learning.

While providing a critique of constructivism, Matthews (2002) posited, “Constructivism is undoubtedly a major theoretical influence in contemporary science and mathematics education.” Despite the difference between objectivists and constructivists, the current science education reform movement recommends a shift to a more learner-centered curriculum. The NSES are written within the framework of a constructivist epistemology. Having the support of a large base of research stemming from the works of notable cognitive psychologists like Piaget, Bruner, and Vygotsky, constructivist-learning theory gained widespread appeal in teacher education programs. The constructivist influence is evident in the content standards (NRC, 1996) mandate to place more emphasis on students’ understanding and use of scientific knowledge, ideas, and inquiry process, and less emphasis on teaching the transmission of information. Even the changing emphasis for the assessment standards, which includes less emphasis on discrete scientific knowledge and more emphasis on scientific understanding and reasoning, underpins a more constructivist epistemology. This shift in focus makes teaching a learner-centered curriculum possible in schools throughout the United States.

Constructivism is a learning theory rooted in experience and a tentative human construct of knowledge based on preexisting information. In a constructivist learning environment as proposed during historical PBL, the role of students in constructing their own understanding is emphasized. Learning is viewed as an active process where building knowledge involves activities requiring both effort and purpose. Once exposed
to a new concept, learners construct individual meaning based on assimilating past experiences with encounters and interactions that occurs when new ideas are exposed. Therefore, for the constructivist, prior knowledge and individual experiences fundamentally impact the learning process (Piaget, 1952; Wadsworth, 1996). Meaning is rooted and organized in experience such that an idea and the learning environment become part of the experience. Classroom experiences afford learners an opportunity to connect prior knowledge to new academic material while challenging misconceptions and enhancing understanding (Garmston & Wellman, 1994).

Social constructivism focuses on the manner in which learners collaboratively build knowledge. The learning process and knowledge construction can be viewed as a result of individuals interacting in social environments to create shared knowledge that is developed by the individual. Vygotsky (1978) put forth ideas about social learning and peer interaction by suggesting that the goal of education is to engage students collaboratively in productive purposeful activities. From this perspective, the activities that foster the development of knowledge are directly linked to the learning that is taking place. During historical PBL instruction, students work collaboratively through open discourse to negotiate meaning.

Lebow (1993) summarizes the constructivist framework as valuing collaboration, personal autonomy, generativity, reflectivity, active engagement, personal relevance, and pluralism. Teachers’ understanding of constructivism has major implications in the implementation of historical PBL. According to Clements (1997), many educators misunderstand constructivism as a type of learning requiring certain teaching practices rather than a philosophy of learning that offers a perspective on how people-all people-
learn, all the time” (p. 198). He offers the following characteristics in an attempt to dispel common myths and define constructivism for teachers: 1) Students’ minds construct ideas through experiencing, listening, practicing, and reflective thinking, all of which need to be balanced to meet the needs of students. 2) The use of manipulatives or hands-on materials may support constructivist teaching when used to support inquiry as opposed to imposing prescribed procedures. 3) Constructing knowledge independently does not mean learning in isolation, but rather that knowledge cannot be directly transmitted to students through words. Constructivist-oriented teachers structure the learning environment to include student-student discourse and reflection. 4) Cooperative learning supports the constructivist view when group work involves students thinking and interacting with content. 5) Every student’s effort in providing responses is respected, but that does not make every student’s answer correct. The goal of a constructivist classroom is to socially construct class solutions that make sense within the system of science and the wider scientific community. Historical PBL was designed within a constructivist framework with elements that Clements suggested representing a constructivist classroom that is dependent on a teacher's facilitation of the learning environment.

According to Savery & Duff (1995), PBL provides one of the best examples of a constructivist learning environment by adhering to the theoretical principles of constructivism. They characterize constructivism in terms of three primary propositions. First, understanding is in the learner’s interactions with the environment. What is learned cannot be separated from how concepts are learned. The learner’s understanding is a function of content, context, activity, and learner goals. Understanding, while individually constructed by the learner, is not shared, but rather tested for the degree of
compatibility. Second, cognitive conflict provides the stimulus for learning, determines the organization of information, and decides the nature of what is learned. The learner has a purpose, which provides the stimulus or goal for learning. Thus, the purpose is central to what is learned by determining what the learner attends to, what the learner assumes in terms of prior understandings, and what understandings the learner ultimately constructs. Third, knowledge evolves through social negotiation and examination of the viability of individual understandings. Collaborative groups provide an important social environment for testing a learners own understanding and evaluating the understanding of others.

Research Design

A qualitative case study method was used to explore secondary science teachers’ facilitation of historical PBL lessons. More specifically, the participants were secondary school science teachers at high schools in a southeastern state. Data collection consisted of the Constructivist Learning Environment Questionnaire (CLEQ) (see Appendix A), semi-structured interviews, and observations of teachers’ facilitation of Historical PBL instructional units.

This study took place in four phases with four secondary science teachers. Prior to participating in research activities, the four teachers participated in a PBL workshop where they learned to design PBL instructional units. The first phase of the study involved teachers completing the CLEQ and participating in semi-structured interviews, which served as follow-up interviews to the CLEQ and a basis to learn about and identify teachers’ perception of their classroom environment. During the second phase of the study, teachers were observed while teaching historical PBL lessons to further identify
successes, obstacles and limitations encountered when implementing the lessons. The third phase of the study involved teachers performing a card sort activity where each teacher denoted successes, obstacles and limitations as either major or minor and categorizes successes, obstacles and limitations into headings such as, instructional design, student learning, and school administration. During the final phase of the study, the four teachers participated in a second interview to discuss, explain, and clarify further the pedagogical practices that influenced their teaching of a historical PBL lesson. Also during phase four, participants took the constructivist learning environment questionnaire (CLEQ) with respect to teaching the historical PBL lesson. Throughout each phase, data was collected, coded, and entered into a database to construct an emerging profile of each teacher’s experience with facilitating a historical PBL lesson and the obstacles encountered. A constant comparative method (Bogdan & Biklen, 2007) was used for data analysis.

Significance of the study

PBL is an instructional strategy based on a constructivist approach to teaching and learning. Through encouraging critical thinking skills, PBL provides an inquiry strategy for investigating real-world issues and problems. As opposed to memorization, recall, and application of facts, PBL focuses on researching and using facts to solve problems. During historical PBL, science is viewed prospectively so that historical facts are researched in context of the world view of the historical time and used to understand the challenges scientists faced during discovery and to comprehend how scientists have solved problems (Allchin, 2000).
Results from this study are significant to several groups of educators. First, the study informs classroom teachers. Workshops such as CERTL’s PBL course provide classroom teachers with a strategy that align with national and state reform efforts and have the goal of influencing teachers’ pedagogical approaches and classroom learning environments. However, teachers’ perceived challenges might limit the inclusion of student-centered constructivist oriented PBL activities. By exposing the barriers associated with facilitating PBL, classroom teachers might be able to anticipate and handle the obstacles encountered during instruction.

Educators who design and conduct professional development workshops will also find this study to be significant. A portrayal of teachers’ experiences with implementing strategies taught is of value to understanding and improving professional development courses. An understanding of the successes, obstacles and limitations classroom teachers experience when facilitating history and nature of science lessons can inform course instructors as they design and implement professional development workshops.

University instructors who work directly with preservice or in-service teachers might find the results of this study significant to their instructional approach and curriculum design. Developing teachers’ understanding of instructional design includes experiences in an inquiry-based learning process and obstacles teachers encounter in the classroom. University courses for preservice and in-service teachers could include discussions on research that focuses on PBL instruction and the challenges resolved by successful teachers. Additionally, professors with a research interest in history and nature of science will find the results of this study significant. Matthews (1992) argued for the inclusion of history and philosophy of science courses in teacher education programs. By
investigating the teaching of history and nature of science using PBL, this study will add to the literature about the successes and challenges faced by teachers who have not taken a course such as Matthews proposed.

Curriculum designers will find the results of this study significant. PBL is based on constructivist learning principles (Savery & Duffy, 1995). For curriculum designers working within a constructivist framework, an understanding of teachers’ perceived successes, obstacles and limitations with inquiry-based activities might influence the way curriculum may be improved and introduced to teachers. Additionally, curriculum designers are tasked with including the history and nature of science standard into the curriculum. Identifying possible successes, obstacles and limitations of both instructional design and the facilitation of history and nature of science content may inform future curriculum development. Ultimately, a curriculum’s success or failure is dependent, in part, on design and classroom implementation.

Administrators should have an understanding of the instructional successes and obstacles teachers encounter when implementing reform-based programs. When transitioning to incorporate inquiry-based PBL curriculum materials into instruction, administrators who understand the process and challenges encountered by classroom teachers can provide necessary support and resources. Thus, administrators can be key to the success of curriculum reform initiatives.

Finally, this study may be significant to students who are directly affected by curriculum initiatives. A well-designed and facilitated problem is critical for learning in a constructivist-based classroom. Well informed teachers who anticipate and can respond when encountering obstacles that impede learning directly influence students’
experiences. Research suggests that student performance, understanding of nature of science, attitudes toward science, interest in the subject, critical thinking, and retention of girls in science programs all increased when using a historical approach to teaching science (Brush, 1989; Matthews, 1992; Russell, 1981). Scholars also suggest that by giving a human face to science, history and philosophy can help to overcome the negative image some students develop of science (Brush, 1989; Matthews, 1992). Students with a positive learning experience might be more motivated to study science and gain a better understanding of how science proceeds.

Summary

Science education reform necessitates a curriculum that aligns with constructivist learning principles to provide students with meaningful experiences, a depth of conceptual understanding, and the contextual learning of science. Allchin (2000) suggests using PBL case studies that give historical context a prominent place in the lesson. PBL embodies constructivist principles by involving students in all aspects of the learning process, which can create pedagogical obstacles for teachers embracing inquiry-based learning. According to Hmelo-Silver (2004), more research is needed to investigate how teachers adapt PBL instruction in the curriculum. While professional development workshops may address many issues for implementing reform-based practices, important details that extend beyond classroom facilitation may often be omitted. The purpose of this study was to identify the understandings, successes and obstacles that teachers experience when implementing historical PBL instruction. A qualitative case study method was used to explore four teachers’ experiences as they implement a historical
PBL instructional unit. By identifying where teachers succeed and struggle with a constructivist philosophy during historical PBL implementation, educators and curriculum designers can improve alignment of the learning environment to constructivist principles and overcome common obstacles by anticipating their existence during PBL instruction.
CHAPTER 2

REVIEW OF THE LITERATURE

Science Education Reform

PBL has a long tradition of use in business, medicine, and law where cases, written as dilemmas, provide a personal history that involve a problem to be solved. The goal is for instructors to help students analyze the facts of the case and discuss both solutions and consequences (Ehrlich, 1998; Fisher, 2000; Herreid, 1994). Thus, PBL involves the idea of “learning by doing” and as such is an inductive rather than deductive process, which focuses on the processes of problem-solving and higher cognitive learning. PBL is deeply rooted in a pragmatic or progressive philosophy. The progressives introduced the term “project” to education during the first part of the 20th century as a means to make schooling more useful and applicable to the world (Barron et. al., 1998).

A progressive science curriculum, influenced largely by the prolific writings of John Dewey and the teachings of William Kilpatrick, endorses teaching scientific advancements and the processes that make achievements possible. Context is central in a progressive curriculum and content lessons are structured around a problem, project, or question (Kohn, 2005). Through the practice of context being central to the curriculum, students are provided with an opportunity to explore their environments, thus realizing Max Wertheimer’s notion of best education (Atkin & Black, 2003). William Kilpatrick
introduced a teaching strategy he termed “project method” where student learning connects to interactions with social and physical environments that peak student interest (Beyer, 1997). According to Kilpatrick, activities of school and community should be intertwined with a goal of leading students to be socially-minded and equipped to become participating and contributing members of a democratic society (Tenenbaum, 1951).

With the formation of the National Science Foundation (NSF) in 1956, a progressive approach to teaching science briefly emerged with NSF providing funds to produce a host of curricula programs such as the Biological Science Curriculum Study (BSSC), Earth Sciences Curriculum Project (ESCP), and Physical Sciences Study Committee (PSSC) to name a few (Atkin & Black, 2003). The reform curricula of the 1950s, with its many acronyms, became commonly referred to as the alphabet soup curricula. Despite the support of NSF, progressive reforms lost favor to discipline-based curriculum after the 1957 launch of Sputnik by the Soviet Union (Donahue, 1993).

The discipline-based or traditional educational experience involves explicit direction, repeated drill and practice, and acquisition of factual knowledge of content. From this perspective content is viewed as an objective body of knowledge stemming perhaps from a rigid view of the “scientific method” (Wallace and Kang, 2004). Therefore, science is often portrayed from a positivist view as a collection of facts, and the processes that authenticate scientific knowledge are given little attention. The reform-based or progressive educational experience involves student-centered exploration, analytical problem-solving, and conceptual understanding. Table 1 presents the different emphases between discipline-based teacher-directed instruction and reform-based student-centered instruction.
Table 1

*Differing Emphasis*

<table>
<thead>
<tr>
<th>Discipline-based curriculum</th>
<th>Reform-based curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowing scientific facts and information</td>
<td>Understanding scientific concepts and developing abilities of inquiry</td>
</tr>
<tr>
<td>Studying subject matter disciplines (Biology, Chemistry, Physics) for their own sake</td>
<td>Learning subject matter disciplines in context of inquiry, technology, science in personal and social perspectives, and history and nature of science</td>
</tr>
<tr>
<td>Separating science knowledge and science process</td>
<td>Integrating all aspects of science content</td>
</tr>
<tr>
<td>Covering many science topics</td>
<td>Studying a few fundamental science concepts</td>
</tr>
<tr>
<td>Implementing inquiry as a set of processes</td>
<td>Implementing inquiry as instructional strategies, abilities, and ideas to be learned</td>
</tr>
</tbody>
</table>

Source: National Science Education Standards. p. 113

An advantage of implementing reform-based curriculum is that such an approach is shown to contribute to personally meaningful learning. Sobral (1995) conducted a double cohort design with a PBL group consisting of 131 university students and a control group, which participated in a conventional instructional approach, containing 120 subjects enrolled in the same program. Researchers used the Course Valuing Inventory (CVI) to measure meaningfulness of the learning experience with total scores being interpreted to reflect learners perceived quality of learning environment and receptiveness. Results revealed that the PBL course, when compared to both previous courses taken by PBL students and courses taken by students in the control group, was
viewed as a personally more meaningful learning experience. The study also concluded that students’ perception of their learning influence their emotional health and motivation to progress through their current field of study.

Since Gardner’s publication of *A Nation at Risk* in 1983, a number of reports and studies claim that U.S. schools fail to educate students for a more sophisticated and rapidly changing scientific and technologically driven world (Aldridge, 1992; Gardner, 1983; Yager & Weld, 1999). *A Nation at Risk* not only reports that high school student achievement scores show a steady decline in science from 1969 to 1977, but also reveals that

Analysts examining these [educational dimensions of risk] indicators of student performance and the demands for new skills have made some chilling observations. Educational researcher Paul Hurd concluded at the end of a thorough national survey of student achievement that within the context of the modern scientific revolution, "We are raising a new generation of Americans that is scientifically and technologically illiterate." In a similar vein, John Slaughter, a former Director of the National Science Foundation, warned of "a growing chasm between a small scientific and technological elite and a citizenry ill-informed, indeed uninformed, on issues with a science component" (Gardner, 1983, p. 10).

With the goal of graduating scientifically literate citizens, the report recommends teaching high school science courses with a focus in 1) concepts, laws, and processes, 2) science inquiry and reasoning methods, 3) applying science to daily life, and 4) societal implications of science and technology.

In 1989 the American Association for the Advancement of Science (AAAS) published *Science for all Americans*, which provides curriculum recommendations to increase scientific literacy for all citizens. The book was the result of AAAS funding a three-year collaboration between members of the scientific community which consisted of hundreds of scientists, philosophers, historians, and educators to determine what
constitutes literacy in science. *Science for All Americans* substantially influenced science curriculum in schools throughout the United States as evident by the document being referenced in the National Science Education Standards (NRC, 1996) and the majority of state curriculum standards. To this end, AAAS provided the groundwork for guiding schools in the United States toward increasing scientific literacy by suggesting that students learn science through inquiring into real-world science problems with societal implications. Hurd, a major proponent of the 1980s movement of socially relevant student interest-centered curriculum, succinctly defines science literacy as “an understanding of science and its application to our social experience” (De Boer, 1991; Spector, 2007).

In 1993, data collection began for the Third International Mathematics and Science Study (TIMSS). One portion of this study, the TIMSS Video Study, compared how eighth-graders are taught in the United States, Germany, and Japan. The study characterizes Japanese lessons as the teacher mediating the relationship between content and student, German lessons as the teacher parceling out the appropriate amount and level of content to students at the right time, and United States lessons as interactions between students and teachers with little incorporation of content. The study portrays lessons in the United States as being at a less advanced level and focusing on learning terms and practicing procedures (Stinger & Hiebert, 1999). PBL provides an instructional strategy for achieving science literacy more aligned to Japanese style lessons where content is central and teachers facilitate student interaction with the material.

An analysis of 50-80 videotape samples in the TIMSS report found that Japan had the most skillful and purposeful teaching where Japanese lessons involved structured
problem solving and continuous refinement of lessons. Students were to solve challenging problems and teachers built scaffolds to help students begin developing methods for solutions. Additionally, coherence was significant in Japanese lessons meaning that lessons told a well-formed story consisting of a sequence of events that fit together to reach a final conclusion. Lesson stories offered the students greater opportunities to make sense of the content (Stigler & Hiebert, 1999). PBL offers teachers a system of teaching similar to the Japanese lessons in that cases form a storyline to frame concepts and discourse that build understanding.

Boaler (1997) conducted a comparison study between a school providing discipline-based instruction to a school implementing PBL instructional methods. Her longitudinal study conducted in two British secondary schools over a three year period compared gains in student understanding of subject matter. The study followed a total of 300 students from the two schools for three years from age 13 to age 16. Students in the two schools were similar in socioeconomic status, had experienced the same traditional instruction prior to the study, and showed similar below average achievement on national tests. Data collection consisted of approximately 100 hours of observing lessons at each school during the first year of the study, yearly questionnaires given to participating students, teacher interviews at the beginning and end of the research period, documents, administered assessments, and standardized national assessment measures. Assessment results from the three-year study significantly favored students at the project-based school with three times as many students scoring the highest possible grade on the national examination (Boaler, 1998).
Constructivist Framework for PBL

Attempts to implement reform-based instruction have had a troubled history. The discovery learning curriculum of the 1960’s, for instance, were not universally adopted despite evidence that such approaches enhanced learning and motivation (Bredderman, 1983; Krajcik, Blumenfeld, Marx, & Soloway, 1994). The lack of success in reforming traditional curriculum has been attributed in part to teacher’s limitations and resistance, which may be attributed to personal views. Duschl (1990), for example, suggests that views of nature of science influence whether teachers regard inquiry activities as beneficial endeavors or as verification events. Since views of teaching and learning influence instructional decisions, successful implementation of reform based instruction like PBL depends on “teachers’ comfort with the premises of project-based instruction” (Krajcik et. al., 1994, p. 489-490).

PBL is a constructivist approach to learning real life problems (van Berkel & Schmidt, 2000) where understanding is a function of content, context, experiences, and learner goals. Constructivism is the philosophical view that knowledge is individually constructed, transmitted by interaction with the environment, and socially developed (Crotty, 1998; Savery & Duffy, 1995). Individually constructing knowledge involves cognitive conflict as a stimulus or goal for learning. Students bring personal experiences with them into the classroom, which have a tremendous impact on how they view the world. Therefore, constructivists reason that learning begins with the prior knowledge, feelings, and skills students bring with them to learning situations (Schulte, 1996). The stimulus provides initial activation of prior experiences, a reason for engaging in the learning environment, and thus, the understanding the learner eventually constructs.
Learners then test the degree to which their individually constructed understandings are compatible with other understandings (Savery & Duffy, 1995). Students have to build up their knowledge with experiences that they use to support their understanding. Teachers assist students by assessing how students are constructing scientific knowledge and by providing guidance through challenging problems (Schulte, 1996). The social environment provides alternative views and additional information for knowledge to evolve as learners test or evaluate the viability of individual understandings and build knowledge and meaning compatible with those understandings (Savery & Duffy, 1995).

Constructivists consider knowledge as simply the most viable interpretation of the experiential world rather than some representation of ultimate truth. Since knowledge constructions are tested to determine how adequately they represent the natural world, not all constructions are equally viable (Savery & Duffy, 1995). Lebow (1993) summarizes the constructivist framework in a manner helpful with interpreting instructional strategies like PBL. He remarks that the traditional educational values of replicability, reliability, communication, and control contrast sharply with the primary constructivist values of collaboration, personal autonomy, generativity, reflectivity, active engagement, personal relevance, and pluralism. The eight instructional principles Savery & Duff (1995) derive for PBL environments from constructivist values are as follows:

1. All learning activities are anchored to a larger task or problem which gives a relevant purpose to learning that extends beyond merely completing assignments.
2. Learners are supported in developing ownership for the overall problem or task. Since the learner’s goals determine what understanding is constructed, these goals need to be consistent with the instructional goals of the course.

3. Authentic tasks are designed to be consistent with the cognitive demands in the discipline being studied. For example, learners should engage in the construction or use of history like a historian rather than learn about history. Similarly, learners engage in scientific discourse and problem solving rather than memorizing science facts or executing scientific procedures.

4. Learning environments are designed to reflect the complex environment learners should be able to function in when the course is completed. This principle is similar to a cognitive apprenticeship approach to learning.

5. Learners are given ownership of the problem solving process used to develop a solution. Teachers challenge the learner’s to think through solving the problem rather than proceduralizing that thinking.

6. Learning environments are designed to value and challenge the learner’s thinking. The learning interaction between teacher and learner should involve a learning scaffold and Vygotsky’s zone of proximal development by asking inquiry, rather than leading, questions.

7. Learners are encouraged to test their ideas against alternative views and alternative contexts. A social environment provides the space for learners to accommodate and, if applicable, incorporate the views of others into their understanding.
8. The learning environment provides opportunities supportive of reflective thinking. To encourage the development of independent self-regulated learners, students engage in reflection on the learning process, strategies for learning, and content learned.

PBL and instruction

Canadian medical schools are given credit for the modern origin of PBL modified for teaching health and natural sciences (Boud and Feletti, 1991; Rhem, 1998; Ross and Hurlbert, 2004). About 35 years ago in Hamilton, Ontario, McMaster University Medical School pioneered the use of case study teaching. The success of this approach inspired other medical schools in the United States and abroad to modify curriculum to include cases that focus on real patient problems (Herreid, 2003).

This classical approach defined PBL as small permanent groups of students working with an instructor on a new case every three class meetings. On the first day the group receives a new case and begin to analyze the preliminary data. With instructor assistance, the group decides on the issues to be addressed and distributes the research workload. When the students return the next day, they share their analysis, receive additional information, and continue their search. The third class meeting brings closure to the case when groups pull together their knowledge and prepare a final report. This classical definition of PBL has been redefined and modified in various ways for different courses (Herreid, 2003).

Sonmez and Lee (2003) offer a functional description more applicable to secondary education defining PBL as
an instructional approach that challenges students to seek solutions to real-world (open-ended) problems by themselves or in groups, rather than learn primarily through lectures or textbooks. More importantly, PBL engages students in developing skills as self-directed learners. Problems are selected to exploit natural curiosity by connecting learning to students’ daily lives and emphasizing the use of critical and analytical thinking skills. (p. 1)

Furthermore, the intent of PBL is to help students achieve the following goals: 1) develop extensive and flexible knowledge that can be applied to future problems, 2) apply metacognitive and reasoning skills when solving problems, 3) develop self-regulated learning skills, 4) become good collaborators by functioning as a member of a collaborative learning team, and 5) develop intrinsic motivation toward learning (Barrows & Kelson, 1995; Hmelo-Silver, 2004).

**Components of PBL**

During PBL instruction students explore information while teachers facilitate PBL instruction and diagnose student understanding, conceptual thinking, content knowledge and processes, and interactions during activities. The teacher’s primary role as a facilitator of PBL instruction is to assist students in collaborative knowledge construction by scaffolding problems and questions to support metacognition and reflection. Facilitative teaching is achieved by modeling problem solving processes, encouraging self-regulated learning, and coaching through effective questioning strategies (Hemlo-Silver & Barrows, 2006; Hemlo-Silver, 2004).

Hemlo-Silver (2004) identifies four main components to PBL instruction: motivating problem/case, teacher as facilitator, collaborative learning, and reflection. Both generating and presenting the problem or case is critical to successful implementation of PBL. The problem should be realistic and activate students’ prior
experiences to motivate students’ need to know, encourage flexible thinking, be complex enough to generate conjecture and argumentation, and require a multidisciplinary solution. Additionally, Savery and Duff (1995) suggest using learning objectives identified by the state to generate problems that raise the concepts and principles relevant to the content domain. When presenting the problem or case, students should be involved in owning the problem so they engage in authentic problem solving. Another significant consideration when presenting the problem is not to provide key information pertinent to the problem, but to highlight the relevance of the problem to the learner.

The most critical component is the facilitator’s role of emphasizing learning through problem solving. Outstanding facilitators are expert learners who model good learning and thinking strategies. They move their students through problem solving stages while monitoring group progress for involvement and encouragement of critical thinking and reasoning, which involves probing students’ knowledge by asking metacognitive type questions such as “Why?” “What do you mean?” “How do you know that’s true?”, rather than using the Socratic method to scaffold the students to the “right” answer through logical questioning. The best facilitators are able to make quick decisions in support of PBL goals, model problem solving processes and self-regulation skills, challenge students to think and help students learn to effectively collaborate (Hemlo-Silver, 2004; Savery & Duff, 1995).

Collaborative learning occurs when group members distribute the cognitive work and participate in discussions, thereby promoting shared knowledge construction and enhancing higher order thinking and problem solving skills. Johnson and Johnson (1999) define cooperative learning as a group of students working together to accomplish shared
goals. Students in cooperative learning groups are responsible for maximizing their own and all other group members learning by perceiving that success only occurs if all members reach their learning goals. Continuous improvement of the quality of learning and teamwork processes becomes the emphasis, which requires five essential elements. Johnson and Johnson (1999) identify the basic elements of a cooperative lesson to include positive interdependence, individual accountability, face-to-face promotive interaction, social skills, and group processing. *Positive interdependence* is what unites diverse students into a common effort resulting in a “one-for-all and all-for-one” mindset. Students work together to maximize learning, share resources, provide support, and celebrate success. *Individual accountability* exists when each student is strengthened through working together and is accomplished when members give assistance, support, and encouragement to each other. *Face-to-face promotive interaction* involves students promoting each other’s success, which facilitates the formation of personal relationships. *Social skills*, such as leadership, decision-making, trust-building, communication, and conflict-management, are a necessary component for cooperative success and require interpersonal and small group skills. *Group processing* involves members discussing goal achievement and working relationships (Johnson & Johnson, 1999; Vermette, 1998).

The final component of PBL instruction, reflection, is key to supporting the construction of extensive and flexible knowledge by helping students “(a) relate their new knowledge to their prior understanding, (b) mindfully abstract knowledge, and (c) understand how their learning and problem-solving strategies might be reapplied” (Hmelo-Silver, 2004, p. 247). Reflection should be an ongoing activity through PBL instruction and ideally increases students’ ability to transfer knowledge.
Research Findings Involving PBL

PBL in a secondary science classroom typically involves using authentic investigations or cases that engage students in meaningful learning, develop inquiry skills, and lead to firmer understanding of content (Chiappetta & Koballa, 2006; Weller & Karp-Boss, 2007). Proponents of PBL emphasize student gains such as improved thinking skills, enhanced cognitive abilities, and increased interest and enjoyment in the content. Other gains mentioned were students’ becoming more independent learners as measured by more frequent users of libraries and other information resources, acquiring life long learning skills, and developing a more holistic approach to content. PBL supporters also characterize PBL educated students as more adapt to change and able to work well as a team member, (Smith, 1995; Sonmez & Lee, 2003). Researchers attributed the increase success of students participating in PBL to effectively activating prior knowledge, promoting meta-cognition through increased elaboration of information, greater understanding and recall, and situating learning in a “real-world” context (Sonmez & Lee 2003).

Challenges teachers face when adopting PBL include inadequate material resources, limited time to create new curriculum, large class sizes, and lack of autonomy from administrators to implement progressive teaching practices (Barron et. al., 1998). Jones (1996; Sonmez & Lee, 2004) groups limitations for implementing PBL into the following six categories:

1. academic achievement (lack of breadth of content covered)
2. amount of instructional time required (inefficiency of PBL to complete required coverage of course material)
3. role of students (student difficulties with self directed learning)
4. role of teachers (teachers unfamiliar with facilitating learning through questioning student logic and beliefs and providing hints when correcting erroneous student reasoning)
5. appropriateness of problems (difficulties in designing problems that keep students on track and encompass both a large goal and specific objectives)
6. appropriate assessment of student performance (unfamiliarity with using a variety of alternative assessment strategies that differ from traditional instruction).

Additionally, critics argue that PBL leads to doing for the sake of doing and suggest that progressive approaches are incompatible with college entrance requirements (Barron et al., 1998).

The limitations of PBL with respect to academic achievement and instructional time was investigated by two middle school teachers, Karoline Krynock and Louise Robb (1996), who questioned if a problem-based unit can provide students with the same or greater depth and breadth of knowledge as a standard unit. Of the 135 eighth grade students participating in the study, 54 students of average intelligence experienced the problem-based class and the remaining students studied the standard science curriculum using lecture and laboratory methods. Upon completion of the unit, students completed a teacher designed final assessment. The two problem-based classes scored marginally higher than the two standard classes; however, one gifted standard class, which spent
more class periods studying the topic in greater depth, scored slightly higher than both
problem-based classes. The teachers concluded that for standard classes the same amount
of curricular content can be taught in a problem-based unit and indicate that PBL
increases higher-level thinking, problem-solving/research ability, and cooperative
learning skills.

Chin and Chia (2004) explored the limitations of PBL with respect to students’
and teachers’ roles. They used an interpretive case study approach to investigate how
questions guided 39 female students working in nine groups of 4-5 each to knowledge
construction in a grade 9 biology course. The authors asserted that “information-
gathering questions sought basic or factual information, bridging questions stimulated
students to link concepts, extension questions steered students to apply their knowledge
or explore beyond, while reflection questions led to evaluative and critical thinking or
decision-making” (Chin and Chia, 2004, p. 722). Another finding was how student-
generated questions guided the process of knowledge construction and helped to identify
isolated pieces of prior knowledge. Chin and Chia posited that the teacher’s role as
facilitator involves scaffolding students through problem-identification and problem
solving by guiding them to formulate questions.

PBL and Scientific Literacy in History and Nature of Science

Using the basic idea of a problem or case-based instructional approach to teaching
is one strategy for achieving scientific literacy as defined by national science education
content standard G, History and Nature of Science. The primary goal of both content
standard G and PBL is learning for capability as compared to learning for knowledge
Acquiring scientific knowledge about how the world works does not necessarily lead to an understanding of how science itself works, and neither does knowledge of the philosophy and sociology of science alone lead to a scientific understanding of the world. The challenge for educators is to weave these different aspects of science together so that they reinforce one another. (p. 145; p. 237)

A PBL approach using historical case studies provides one possibility for merging philosophy and sociology of science with content knowledge.

Harvard Project Physics (HPP) was the first curriculum program to include the history and cultural context of science. Aikenhead and Brush wrote how students who took part in the HPP gained an appreciation of the various ways scientific knowledge is pursued and learned to think outside the standard scientific method. Additionally, they noted that students’ appreciation for the imagination, confirmation, and instrumentation of science did not hinder their knowledge of the discipline (Matthews, 1989). Research also suggests that student performance, understanding of nature of science, attitudes toward science, interest in the subject, critical thinking, and retention of girls in science programs all increased when using a historical approach to teaching science (Brush, 1989; Matthews, 1992; Russell, 1981). Scholars suggest that by giving a human face to science, history and philosophy can help to overcome the negative image some students develop of science (Brush, 1989; Matthews, 1992).

Martin (1972) states that the “aim of science education ought to be to produce people imbued with the spirit of science who manifest that spirit in all relevant contexts.” He suggests conceiving of science education much more broadly to include ideas like consumer and moral education, which is similar to Hurd’s definition of scientific literacy.
as an understanding of science and its connection to society. Using historical case studies provides the opportunity for students to discuss moral issues like the use of atomic bombs or experimentation with animals. Additionally, Martin suggests that history and philosophy of science can assist students in understanding science inquiry, explanations, definitions, and observations.

While the main argument for promoting history and philosophy of science in science education is to promote better science learning, proponents of history and philosophy of science do offer some reasons for concern. One caution is not to provide a simplistic caricature of the historical process when revealing the subject matter (Matthews, 1992). The history of science can be complex and an over simplification can grossly distort science understanding. One solution to this issue is to provide adequate understanding to teachers. Hodson (1988, p. 21) remarked, “teachers’ understanding of the nature of science is little better than that of their students” which can be improved through education courses. Such education courses can provide an inquiry line of scholarly research.

With the inclusion of history and nature of science in the NSES, Science educators are incorporating more history and philosophy of science in both preservice and in-service teacher programs. This provides several lines of inquiry for scholarly research on the topic such as methods for training of teachers, preparation of classroom materials, and the use of historical case studies in classrooms. One particular line of research might include how teachers facilitate the implementation of historical case studies through a PBL approach. Some sub-questions could focus on the pedagogical
concerns that arise when historical case studies are taught and the degree to which teachers are able to address nature of science complexities.

When teaching historical cases, context requires a prominent place in the lesson if applying history to teaching science is to assist with scientific literacy in the history and nature of science. Allchin (2000) contends that rational reconstructions can misrepresent history and become misleading about both the history and process of science. His recommendation is to place a scientific problem in the full historical context to avoid distorting the subject being illuminated. First, viewing science prospectively in context of the world view of the historical time, rather than retrospectively, respects and presents the richness of scientific practice. Second, the elements of scientific discovery, such as generating hypotheses, searching for relevant information, designing and critiquing experiments, elaborating on alternative explanations, and struggling with experimental anomalies, are exposed so that students feel as if they are looking over a scientist’s shoulders as they work, while making decisions in their absence. Third, illustrating that science sometimes leads to wrong conclusions but right ideas contributes to understanding the nature of scientific justification and its limits, the tentative nature of scientific knowledge, and the potential for simple or early models to be misleading (Allchin, 2000).

History and Nature of Science in the NSES

PBL instruction lends itself to teaching content standard G of the national science education standards, which is titled History and Nature of Science. Specifically, the standard states,
The *National Science Education Standards* use history to elaborate various aspects of scientific inquiry, the nature of science, and science in different historical and cultural perspectives. . . . Teachers of science can incorporate other historical examples that may accommodate different interests, topics, disciplines, and cultures--as the intention of the standard is to develop an understanding of the human dimensions of science, the nature of scientific knowledge, and the enterprise of science in society--and not to develop a comprehensive understanding of history (NRC, 1996, p. 200).

The goal of this standard is for teachers to use history to assist students with developing an understanding of a) science as a human endeavor, b) nature of scientific knowledge, and c) historical perspectives (NRC, 1996). A PBL approach to teaching offers a strategy to meeting the three goals of standard G of the national science education standards.

*Science as a Human Endeavor*

PBL offers a strategy for placing science as a human endeavor as the central context for learning. The AAAS (1993) asserts that if science literacy is to be an aim of curriculum, teaching science as a human endeavor deserves a prominent place in the curriculum. The authors suggest that students are less likely to reject scientific claims out of hand or accept them uncritically if they have an understanding of how scientists conduct their work and reach scientific conclusions. Students with a good understanding of how science operates and a basic comprehension of key science concepts are more apt to follow how science progresses during their lifetimes. By making explicit the study of science as a way of knowing, students’ misconceptions about science that narrowly focuses on laws, concepts, and theories of science can be dispelled (AAAS, 1993).

The fundamental concepts for teaching students to view science as a human endeavor involve three main principles. First, the scientific enterprise includes
contributions from individuals and teams. Science or engineering is conducted through individual field studies or complex networks of hundreds of people laboring on a technical or major scientific problem. Science can be a fascinating and intellectually rewarding career or hobby. Second, scientists have ethical traditions. The methods and outcomes of science investigations are peer reviewed, truthfully reported, and made public. Scientists who violate ethical traditions are censured by fellow scientists and, as such, are atypical. Third, society, culture, and personal beliefs influence scientists. Thus, science is a part of society and not separate from society (NRC, 1996).

Nature of Scientific Knowledge

PBL poses a challenge for students to struggle with which provides an explicit experience with NOS. AAAS (1989; 1993) defines NOS as the means (observing, thinking, experimenting, and validating) used to develop peoples’ interconnected ideas about the natural world which distinguishes science from other ways of knowing. NOS is further described within three categories: the scientific world view, scientific inquiry, and the scientific enterprise. According to AAAS’s community of scientists, the scientific worldview consists of scientific ideas that are understandable, subject to change yet durable, and unable to completely answer all questions. While scientific inquiry between different disciplines (i.e. Biology, Chemistry, Physics) employ similar processes, the methods used may differ. The committee’s consensus view of scientific inquiry is that science demands evidence, is a mix of logic and imagination, explains and predicts, attempts to identify and avoid bias, and is not authoritarian. Additionally, NOS provides a contemporary world view of scientific activity and suggests that science is a complex social activity, organized into content disciplines and conducted in various institutions,
conducted through generally accepted ethical principles, and concerned with public affairs (AAAS, 1989; AAAS, 1993).

Within the last 15 years of science education literature, researchers have reported both explicit and implicit tenets of NOS. The result has lead to many scholars claiming a concise description of NOS representative of all of scientific knowledge and disciplines (Schwartz, Lederman, & Crawford, 2004). Additionally, McComas, Almazroa, and Clough (1998) constructed a consensus view of NOS after analyzing science objectives from eight international science standards documents. These NOS tenets along with the NSES for nature of science are presented in Table 2.

Science in Different Historical and Cultural Perspectives
Problem-based learning that makes use of historical case studies offer an opportunity for students to view science in different historical and cultural perspectives. The AAAS (1989) provides two reasons for including knowledge of historical perspectives in a science curriculum. First, the authors contend that understanding generalizations about the operation of the scientific enterprise would be empty without concrete examples. Second, the authors claim that some historical episodes of scientific endeavors are of “surpassing significance to our cultural heritage” (AAAS, 1989, p. 145; AAAS, 1993, p. 237). All human cultures study nature and posit understandings of science, and as such, have contributed to the scientific enterprise. The AAAS (1989) recommends teaching historical and cultural perspectives involving significant events that demonstrate the evolution and influence of scientific knowledge while illustrating historical themes and holding cultural salience.
The fundamental concepts for teaching science in different historical and cultural perspectives involve four main principles. First, diverse cultures contribute to scientific knowledge and technological inventions. The rapid development of modern science

Table 2

**Tenets of NOS**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Scientific knowledge often, but not always, proceeds through observation, experiments, logical arguments, and skepticism</td>
<td>Science uses empirical standards, logical arguments, and skepticism to reach the best possible explanations of the natural world</td>
</tr>
<tr>
<td>There are many ways to do science (no universal step-by-step scientific method exists)</td>
<td>Scientific explanations must be consistent with experimental and observational evidence about nature</td>
</tr>
<tr>
<td>Theories do not become law; theories and laws are fundamentally different</td>
<td>Scientific explanations, when appropriate, make accurate predictions about systems being studied</td>
</tr>
<tr>
<td>Observations are theory-laden</td>
<td></td>
</tr>
<tr>
<td>Science involves accurate record keeping, is peer reviewed, and repeatable to check, but not guarantee, against bias</td>
<td>Scientific explanations are logical, respect the rules of evidence, open to criticism, report methods and procedures, and make knowledge public</td>
</tr>
<tr>
<td>Scientists are imaginative</td>
<td>Explanations of the natural world based on myths, personal beliefs, religious values, mystical inspiration, or superstition are not scientific</td>
</tr>
<tr>
<td>Science proceeds through contributions from people of all cultures and consists of both social and cultural traditions</td>
<td></td>
</tr>
<tr>
<td>Scientific knowledge is durable yet tentative</td>
<td>Scientific knowledge is subject to change as new evidence becomes available</td>
</tr>
<tr>
<td>Social and historical events influence scientific ideas</td>
<td></td>
</tr>
<tr>
<td>New scientific knowledge is clearly and openly reported</td>
<td>Core ideas of science are subjected to a wide variety of confirmations are unlikely to change</td>
</tr>
<tr>
<td>Science proceeds through curiosity and attempts to explain natural phenomena</td>
<td>Ideas from incomplete data or understanding may eventually change current ideas or resolve existing conflicts</td>
</tr>
</tbody>
</table>
History reveals that science is dynamic and on-going; has evolutionary and revolutionary characteristics. Incomplete scientific ideas are normal, and situations of fragmentary information provide an opportunity for making great advances.

Science and technology are interrelated beginning in Europe several hundred years ago significantly contributed to the industrialization of both Western and non-Western cultures. Non-European cultures have also advanced scientific ideas and solved human problems. Second, science generally changes through small modifications in existing knowledge. Scientists and engineers incrementally advance human understanding of the world and our ability to meet human needs. Learning about the daily work of scientists to advance science in their area of study provides insight into NOS. Third, some science and technological advances have important and long-lasting effects on science and society. Some examples include the Copernican revolution, Newtonian mechanics, Plate tectonics, Atomic theory, Biological evolution, Germ theory, Molecular biology, Quantum theory, and medical and health technology. Fourth, scientific knowledge evolves over time by building on earlier knowledge (NRC, 1996).

**PBL Workshop**

Presenters at the professional development workshop at the CERTL instruct in-service teachers to design and implement PBL. The center’s mission is to improve the quality of science, mathematics, and technology education in a southeastern state community. Specific goals include deepening student’s understanding of content subject matter, creating and sustaining student interest in math and science subject areas.
particularly within underrepresented populations, and attracting students to careers in science-related fields.

The CERTL defines PBL as a learning/teaching methodology that uses problems as a starting point for acquiring new knowledge and a strategy to create learning experiences that reinforce existing knowledge. Three key characteristics of PBL are 1) problems are real world in nature to the learner and the value of knowing the information is evident to the learner, 2) problems activate prior knowledge enabling learners to attach new content to existing information or previous experience, and 3) problems mimic the application of new information. According to the CERTL, the underlying philosophy of PBL is first; learners prefer to participate in decision-making about their learning. Second, learners bring lots of information to new learning. Third, PBL reinforces existing knowledge and creates a starting point for acquiring new content. Finally, fourth, PBL problems enhance the integration of new information.

Through PBL, the CERTL aims to create learners who know what they know with confidence, know what they do not know with confidence, can effectively and efficiently access new information and integrate it with existing knowledge, and apply the new information to problem resolution. To accomplish these aims, the following structure is taught during the PBL workshop:

- A student reads the problem aloud to their group.
- Students identify the facts, “What they know” from reading the problem.
- Students identify learning issues, “What they don’t know.”
- Students identify what could be going on, their ideas to move them forward in exploration.
• Students make decision about how to proceed.
• Students acquire new information through research or additional resources.
• Students test their ideas against new knowledge, re-rank ideas as needed.
• Students continue to acquire new information and integrate it with what they know.
• Students arrive at most viable and defendable hypothesis/solution.

The structure for a PBL lesson is taught as a cyclical process as depicted by the CERTL’s PBL process chart as shown in Figure 1. While the process begins with the problem and can take many paths toward completion, teachers certified through the CERTL to implement PBL typically follow the process in the path outlined in the course structure. The CERTL has a strong history of external funding sources to support the development and dissemination of PBL to enhance science and mathematics curriculum, to improve student performance in math and science courses, and to increase student attraction to math, science, and related subject fields. In 1996 the center was established through funding from the National Science Foundation. Additional support since 1996 has come from Howard Hughes Medical Institute funding to support PBL materials development, Eisenhower Professional Development funding to support teacher professional development, Burroughs Wellcome Fund support for student enrichment programming, a National Institutes of Health Science Education Partnership Award to support teacher professional development and student enrichment, and funding from the State Department of Public Instruction to further support PBL materials development. The vast and continued support from a variety of funding sources demonstrates the importance and
success of CERTL in accomplishing their mission of promoting quality teaching through PBL instruction.

Figure 1. PBL Process Chart

Summary

A PBL learning approach is being implemented throughout school curriculum on the basis that such reform efforts will increase scientific literacy and has the potential to provide a better understanding of the history and nature of science. A review of PBL literature suggests student gains in cognition, development of skills, independent learning, cooperation, and motivation (Chiappetta & Koballa, 2006; Smith, 1995; Sonmez & Lee, 2003; Weller & Karp-Boss, 2007). However, teachers often experience challenges when attempting to facilitate PBL (Barron et. al., 1998; Jones, 1996; Sonmez & Lee, 2004).

Thomas (2000) and Hmelo-Silver (2004) agree that while there is much literature on PBL in post-secondary education, there is little research on PBL in the K-12
education. Hmelo-Silver (2004) states, “It would be naïve to believe that the medical school model of PBL could be incorporated into other settings without considering how to adapt it to the local context, goals, and developmental level of learners” (p. 260). She advises that the self-directed learning component of PBL could prove problematic for learners challenged to apply metacognitive strategies. Understanding how teachers adapt PBL, scaffold learning, and incorporate “just-in-time” direct instruction are important research issues in need of empirical studies to inform educators about adapting PBL into the secondary curriculum.
CHAPTER 3

METHODOLOGY

Introduction

PBL is a curriculum and instructional strategy that teachers can implement to create a constructivist classroom environment (Gagnon & Collay, 2001; Torp & Sage, 1998). This case study focused on teachers’ facilitation of a problem-based instructional unit designed to provide secondary students experiences with a historical perspective of science as they master science inquiry skills and science concepts. There were two goals of this study. The first goal was to identify how secondary science teachers’ perceived and actual instructional practices align with constructivist principles. The second goal of this study was to identify the successes, obstacles, and limitations teachers encounter in their educational environment when teaching historical PBL lessons. Successes were defined as events of desired achievement, obstacles as events that interfered with or hindered learning, and limitations as events that restricted or weakened learning.

A qualitative interpretive case study guided this research study. An interpretive qualitative approach to research involves exploring the lived experience (Merriam, 1998). Yin (2003) defines case study as the most effective way to identify, document, and explore the pedagogical practices of teachers. A case study research design provides the researcher with an approach to study, observe, and analyze the classroom’s complex-learning environment. Yin’s case study definition corresponds with the purpose of this
study. The most effective way to identify the pedagogical practices and teachers’ perceptions of the learning environment is to collect evidence and data describing teachers’ instructional practices and obstacles encountered while facilitating a historical problem-based instructional lesson.

Yin (2003) describes three conditions inherent to selecting the case study research design. The first condition of the case study is the “type of research question posed” (p. 5). The case study favors the use of “how”, “why” and sometimes “what” questions. In this study, the researcher investigated how teachers’ PBL instructional practices align with constructivist principles and how teachers facilitate historical PBL instruction. Additionally, two subquestions were addressed in this research. The first subquestion was why teachers might experience pedagogical successes, obstacles, and limitations with facilitating historical PBL lessons. The second subquestion was what is the possibility of teaching history and nature of science through PBL instruction.

The second condition to be met for employing the case study is the extent of control over behavioral events. The case study provides the researcher with little to no control over actual behavioral events (Paxton, 2002; Yin, 2003). This study involved a detailed description of instructional practices with no control over the events that occur when teachers were facilitating a historical PBL lesson.

The third, and final, condition for selecting case study design is the degree of focus on contemporary events. The unique strength of case study design is in the strategy’s ability to include a range of data collection such as documents, artifacts, interviews, and observations when studying contemporary events (Bogdan & Biklen, 2007; Paxton, 2002; Yin, 2003). The setting for this study was in contemporary
secondary classrooms. Several forms of data collection techniques and activities were used including interviews, questionnaires, card sorts, and participant-observation.

Yin (2003) states that the distinct advantage for the case study is when “a “how” and “why” question is being asked about a contemporary set of events, over which the investigator has little or not control.” This study investigated the classroom learning environment where the researcher had no influence on teacher facilitation of lessons. Therefore, the goals of this study was best reached by using a case study design fulfilling the three aforementioned conditions.

Context of the Study

The researcher investigated the classroom environments of four teachers at three different schools as the context for the study in this holistic multiple case study design research investigation. Using what Yin (2003) refers to as a holistic multiple-case design, each case was carefully selected to serve the specific purpose of predicting similar results within the overall scope of the study. Thus, each participant in the study was similarly trained in the implementation of PBL, taught in the same school district, and facilitated the same PBL instructional unit on classification of living organisms. However, participants’ years of experience with both teaching science and using PBL as an instructional strategy varied, as did the students in each teacher’s classroom. The goal of this study was not to determine the prevalence of constructivist practices or pedagogical successes, obstacles and limitations, but to investigate the research questions with respect to individual cases and to explore the extent of replication across cases.
The participants in this study were employed in secondary schools located in a county in the southeastern United States with an estimated population of 340,000. At the time of this study the median household income of residents was $42,000. The total per pupil expenditures for the district in 2008 was $7,762. Forty-four percent of the students in this county were eligible for free or reduced-price lunch program. Major ethnic groups living in this county included Caucasian (45%), African American (31%), Hispanic or Latino (17%), Asian/Pacific Islander (2%), and American Indian/Alaskan Native (<1%). District high schools reported, on average, an enrollment of 1,025 students with an average ratio of 14 students per teacher. In 2007, biology was the only end of course science test given to all students in the county where this study took place. Results for state end of course tests in biology for Forsyth County reveal that 62% of the students passed in 2007, which is 3% below the state average.

Each teacher taught a multi-day lesson on the classification of kingdoms using historical PBL instructional strategies. Prior to beginning the lesson, teachers invited students to write down as many types of organisms as came to their minds. After sharing some of the students’ ideas the teacher prompted the students with the following question: How are the multitudes of living things related? The teacher allowed for a brief discussion among the groups and then opened it up the discussion to the whole class. The students thought of interesting answers. For example, one student talked about how one could easily overlook how bacteria and humans need each other to survive. This sparked questions on how symbiosis between organisms is possible. The teacher was able to focus the discussion on the next question: How can order be created out of the chaos of diversity? The teacher allowed for a few minutes of group discussion before
proceeding. The teacher then presented the case by explaining that early taxonomists placed all organisms into either the plant or animal kingdom. However, Copeland, a biologist and Whittaker, an ecologist, criticized this system because it did not accurately reflect important biological relationships. Both scientists created different systems for classifying living organisms and the students were to investigate this problem and provide an expert opinion on classification systems while preparing a historical timeline.

Students were then placed into cooperative learning groups of three to four students per group and given the first problem to read. The problem places students into the role of a taxonomist in 1956, and explains how Copeland’s four-kingdom classification scheme categorized organisms according to evolutionary relationships, while Whittaker’s three-kingdom classification system was based on an organism’s ecological role as producer, consumer, or decomposer. At first the students struggled to understand the problem and several groups had questions for the teacher. The teacher was careful not to give away any answers and allowed the groups to sort out the problem on their own. Slowly some students became excited about being a Taxonomist as groups began to create a list of facts presented in the problem and shared them with the class as the teacher recorded the class list on the board. Next, the students discussed what they needed to know more about to determine the best system for classifying organisms. Some of the students struggled to understand this step and the teacher provided additional small group guidance. Following this activity, students were provided with different resource sheets to help answer their questions. When students finished their research, the teacher facilitated a class discussion of the students’ findings followed by students’ drawing the first component of the historical timeline. Each group was provided with a large piece of
butcher paper where they drew the first component of the historical timeline. Before class ended, a few groups of students asked if they could participate in more group learning activities.

The next lesson began with students being given the second problem, which is set in 1957 after Whittaker immersed himself in the taxonomic literature of unicellular organisms and recognized that, similar to Copeland, he needed to add a fourth kingdom. While Whittaker used the same kingdom names (Plantae, Animalia, Fungi, and Protista), the organisms he placed in the Protista kingdom differed from Copeland. The second lesson went more smoothly as students appeared more comfortable with the PBL process. Microscopes with slides of fungi and protests were set up around the room for students to observe throughout the lesson. The students assembled into the same groups as the first lesson and began to identify and share key facts. They then started recording questions that need to be answered. Some of the questions that they recorded were: How different were the organisms that Whittaker placed in the Protista kingdom than Copeland’s? Some of the students inquired about how could they even tell the differences when the organisms were microscopic. When the groups began to research this second time, they seemed to be more in charge of the research and did not depend as much on the teacher. After the research was concluded the teacher facilitated a discussion. The students were then asked to add Whittaker’s new system to their historical timeline.

Lesson three began with an introduction to the third problem where students discovered that by 1969 Whittaker became convinced that his Protista kingdom needed to be split into two separate kingdoms, Protista and Monera. As in the preceding problems, students identified and shared facts, and recorded and researched questions. Students
realized during this problem that some species (eg. green and brown algae) have characteristics of two different kingdoms (eg. plantae and protista). Students engaged in a class debate to determine how these organisms can best be classified. The students uncovered interesting evidence to support why these two organisms should belong to Plantae or to Protista Kingdom. After a class discussion, students added a fourth system to their historical timeline. While they are adding this fourth system to the timeline the students appeared to have an epiphany in their understanding of how a classification system evolved over time through the different ideas of scientists.

The problem in the fourth and final lesson presented to students was Whittaker’s struggle with the conflicting demands of portraying a classification system that would reflect important ecological principles while still accurately portraying evolutionary relationships. Students were also introduced to Carl Woese and his 1977 ideas for a six-kingdom classification system. Students followed the PBL routine of identifying and sharing facts, recording and researching questions, and sharing findings in a class discussion. Students then completed their historical timeline and wrote a paragraph explaining and justifying how and why they would classify organisms in the 21st century. In their paragraphs students justified why such organisms as the carnivorous Venus Fly trap belonged in the plant kingdom and how some algae were plants and others were protists. The historical PBL unit ended with students submitting their assessment products. Students seemed to grasp the challenge of designing a classification system that includes the unusual prokaryotes, reflects important ecological principles, accurately portrays evolutionary relationships, and is convenient to use, and that the currently accepted six-kingdom system of classification is likely to be revised in the future.
Researcher’s Role

Interpretive research seeks to gain a better understanding of “the human condition and experience” (Merriam, 1998, p. 6). As the researcher of this study, my goal was to accurately describe participants’ experiences with facilitating historical PBL instructional units through various means of data collection. As the researcher with the primary means for collecting and interpreting evidence, my commitment was to provide an authentic, balanced, and fair portrayal of each case in this study (Patton, 2002). Producing a credible study required acknowledging and reporting my selective perceptions, personal biases, and theoretical predispositions throughout this study (Patton, 2002).

As a former secondary science teacher, I have experience with implementing PBL instructional units. Therefore, I have certain perceptions, biases, and predispositions about facilitating PBL that undoubtedly influenced my attention during this study. I view education as providing an experience where students can take ownership of their learning and PBL as one of many strategies to accomplish this goal. How teachers facilitate PBL greatly influences students’ learning experience. By viewing data collected through a constructivist lens, I am able to gain insight into the successes, obstacles, and limitations teachers encounter when implementing PBL.

Qualitative inquiry for this study involved my direct experiences with the participants through classroom observations and interviews. As such, I gained insight into the teaching practices of participants by learning through empathic neutrality in a direct reflective process (Patton, 2002). Direct reflection and emphatic neutrality involves using the researcher’s direct experiences; being nonjudgmental or neutral; showing openness,
respect, awareness, and responsiveness; and being fully present and mindful during observations. The purpose of this study was to gather information and not to change each participant being interviewed. However, collecting qualitative data can be transformative for the interviewees thereby requiring ethical consideration. Prior to contacting participants regarding participation in this investigation, I submitted a request for approval to conduct this study to the institutional review board (IRB). IRB committee members review, request modifications, and approve research proposals to ensure the protection of human participants. Upon approval from the IRB to conduct this study, I secured informed consent from participants. Additional ethical responsibilities beyond the scope of IRB included respecting participants by not deceiving them, being unfailingly polite, and asking permission when quoting (Rubin & Rubin, 2005). Participant confidentiality was protected at all times through the use of pseudonyms and untraceable identification labels thereby masking all identifiers.

Participants

The participants in this study were selected based on purposeful and convenience sampling. Purposeful sampling presupposes that the researcher is interested in discovering, understanding, and gaining insight into a qualitative problem; therefore, participants were chosen based on their special expertise and competence (Merriam, 1998). Defining the criteria for each participant of the study assisted with exploring the degree of replication. To establish teacher expertise and competence in teaching PLB instruction, the selection criteria for this research project were secondary science teachers with at least three years of teaching experience, degrees in science education, and State
Licensure. In addition, the teachers completed a PBL workshop conducted by the Center for Excellence for Research, Teaching and Learning (CERTL). This case study research project consisted of four secondary science teachers. One of the participants had more than five years of experience facilitating PBL, two of the participants had three to five years of experience facilitating PBL, and one participant had fewer than three years of experience facilitating PBL. For convenience, the participants were selected from high schools in a southeastern state.

Research Activities and Data Collection

“Usually we want to learn what the selected case does – its activity, its functioning. We will observe what we can, ask others for their observations, and gather artifacts of that functioning” (Stake, 2005, p. 452). Obtaining data to support the purpose of this study requires accumulating data from a variety of sources. The sources of data that were collected for this study include questionnaires, interviews, participant-observations, and card sort artifacts as presented in Figure 2. Table 3 presents how the research activities correspond with the research questions.
Table 3

*Data Sources For Research Activities*

<table>
<thead>
<tr>
<th>Phase 1 Research Activity</th>
<th>Research Question 1: Constructivist Practices</th>
<th>Research Question 2: Obstacles and Successes Encountered</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: CLEQ</td>
<td>Each teacher completed a questionnaire and answer interview questions that focused on constructivist practices</td>
<td>Each teacher answered interview questions that focused on the anticipated successes and obstacles with facilitating historical PBL lessons.</td>
</tr>
<tr>
<td>B: Individual Interviews</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Member Checking</td>
<td>Participants were asked to review transcripts.</td>
<td></td>
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</tbody>
</table>
### Phase 2 Research Activity: C: Classroom Observations

I observe instructional activities and collect field notes to characterize the facilitation of PBL lessons. 
I collect field notes to record obstacles and successes encountered with facilitating historical PBL lessons.

**Member Checking**
Discussed observations with participants.

### Phase 3 Research Activity: D: Card Sort

I aligned teachers' card sort to constructivist practices. 
Each teacher created obstacle, limitation and success cards, group the cards into major or minor events, and then categorize the cards.

**Member Checking**
Discussed card sort with participants.

### Phase 4 Research Activity: E: Individual Interviews F: CLEQ

Each teacher completed a questionnaire and answered interview questions that focused on how teachers implemented constructivist practices when facilitating historical PBL lessons. 
Each teacher answered interview questions that focused on the obstacles encountered when facilitating historical PBL lessons.

**Member Checking**
Participants were asked to review draft analysis.

---

**Phase 1 Research Activity: CLEQ and Interviews**

Phase 1 research activity involved the collection of two sources of data. First, participants were given a questionnaire to determine teacher perspectives on their classroom learning environment when using PBL instruction. The 42 questions asked in the questionnaire (see appendix A) are divided into six scales each containing seven questions. The six scales of constructivist learning environments in the science classroom are personal relevance, scientific uncertainty, critical voice, shared control, student
negotiation, and student attitude. Additional information about the CLEQ is presented at the end of this section.

The second source of data to be collected during phase 1 included participant interviews. According to Rubin and Rubin (2005), “qualitative interviews are conversations in which a researcher gently guides a conversational partner in an extended discussion” (p. 4). Interviews provide the researcher with a portrayal of specific events or processes that can not be directly observed. As such, interviews were a crucial part of this research study by providing insight into participants’ perspectives. Each teacher was interviewed individually. Interviews were conducted for approximately 20-30 minutes in length and include questions related to constructivist practices during PBL instruction. The interview guide presented in Appendix B lists guiding topics and questions to be explored during each interview and were used to elucidate and illuminate participants perceptions of PBL and constructivist practices (Patton, 2002).

Phase 2 Research Activity: Classroom Observations

Phase 2 research activity entailed participant-observations of each teachers’ classroom facilitation of historical PBL instruction. Dewalt and Dewalt (2002) define participant observation as “a way to collect data in naturalistic settings by ethnographers who observe and/or take part in the common and uncommon activities of the people being studied” (p. 2). Data collected from observations consisted of “activities, behaviors, actions, and the full range of interpersonal interactions and organizational processes” (Patton, 2002, p. 4) that were part of participant’s classroom learning environments.

Teachers spent approximately one week teaching a historical PBL lesson. Typically, classes met every day for either 50 minutes or 90 minutes. Observations were
conducted in one to two class periods per day every day during the historical PBL instruction. Attending the majority of the instructional activity provided the necessary data for triangulation of evidence during data analysis. In addition to field notes, the constructivist classroom observation form presented in Appendix C lists types of instructional activities that were documented during each observation and were used to record participants facilitation of PBL and constructivist practices. The constructivist classroom observation form was modeled after the differentiated classroom observation scale (Cassady, Speris, Adams, Cross, Dixon, and Peirce’s; 2004). The goal for using the form was to characterize participating teachers classroom learning environment with respect to constructivist learning principles. The form included a header for recording the location and time of the observation and was divided into three sections: a table for scoring learning activities and behaviors, a chart for describing both teacher and student actions, and a series of lines for writing additional field notes.

Phase 3 Research Activity: Card Sort

Phase 3 research activity had participants completing a card sort activity to identify successes, obstacles, and limitations encountered during historical PBL instruction, group obstacles as major or minor, and categorize successes, obstacles, and limitations. Each teacher was asked to create a list of pedagogical successes, obstacles, and limitations encountered during the facilitation of their historical PBL instructional unit. After teachers finished teaching the unit, they transferred their list to a set of red, yellow, and green blank 3x5 index cards as follows: successes to green cards, obstacles to yellow cards, and limitations to red cards.
Participants labeled each card with an appropriate category such as instructional design, student learning, and school administration. Teachers then divided the cards into two categories: major and minor events. When this task was complete, each teacher constructed four lists with respect to facilitating historical PBL lessons as follows: 1) a major obstacle and limitations list, 2) a minor obstacle and limitations list, 3) a major success list, and 4) a minor success list.

*Phase 4 Research Activity: CLEQ and Interviews*

Phase 4 research activity replicated the research activities in phase 1. The first source of data collected during phase 4 was to give participants the same questionnaire given at the beginning of the research study to determine if participants’ perception of historical PBL classroom learning environments were different from the beginning of the study. The second source of data during phase 4 included participant interviews. The same interview guide used in phase 1 was used to guide the exploration of participants’ perception of historical PBL and constructivist practices.

*CLEQ Instrument Description*

The Classroom Learning Environment Questionnaire (CLEQ) was created from Taylor, Fraser, and White’s (1994) Constructivist Learning Environment Survey (CLES). The CLES was originally developed to enable “researchers and teacher-researchers to monitor their development of constructivist approaches to teaching school science . . .” (Taylor, Fraser, & Fisher, 1997, p.293). The original version of the CLES contained 30 items measuring five key dimensions of a critical constructivist learning environment measured through students’ perceptions. Subsequent revisions to the original CLES include a version containing 42 items and a version measuring the six key dimensions.
through teachers’ perceptions of the classroom learning environment. Prior to this research study, the CLEQ was piloted to seven preservice teachers and comments were gathered from participants taking the CLEQ. As a result four items required rewording. The NSTA Standards document (NRC, 1996) was used to guide modifications for the CLEQ science uncertainty scale items.

The CLEQ instrument that was used in this study contains 42 items with seven items measuring each of six key scales of constructivist learning: personal relevance, scientific uncertainty, critical voice, shared control, student negotiation, and student attitude through teachers’ perceptions. The response alternatives and associated number value for each item are Almost Always (5), Often (4), Sometimes (3), Seldom (2), and Almost Never (1). Two of the scales use only positively-worded item statements and four of the scales incorporate both positively and negatively worded item statements.

The CLEQ instrument was used to evaluate and monitor teaching environments, as perceived by teachers, in each of six scales designed to measure constructivist approaches. Scale one, Personal Relevance (PR), determines teachers’ perception of the relevance of science instruction to students’ out-of-school lives by measuring the capability of the teacher to guide instruction through meaningful context of students’ backgrounds and everyday interests (Taylor, et al., 1997). Scale two, Scientific Uncertainty (SU), “assesses the extent to which opportunities are provided for students to experience scientific knowledge as arising from theory-dependent inquiry involving human experience and values, and as evolving, non-foundational, and culturally and socially determined” (Taylor, et. al., 1997, p. 296). Scale three, Critical Voice (CV), “examines the extent to which a social climate has been established in which students feel
that it is legitimate and beneficial to question the teacher's pedagogical plans and methods, and to express concerns about impediments to their learning” (Taylor, et al., 1997 p. 296). Scale four, Shared Control (SC), is “concerned with students being invited to share with the teacher control of the learning environment, including the articulation of learning goals, the design and management of learning activities, and the determination and application of assessment criteria” (Taylor, et al., 1997, p. 296). Scale five, Student Negotiation (SN), assesses the extent to which opportunities exist for students to explain and justify to other students their newly developing ideas, to listen attentively and reflect on the viability of other students' ideas and, subsequently, to reflect self-critically on the viability of their own ideas (Taylor, et al., 1997, p. 296). Scale six, Student Attitude (SA), measures teachers’ perception of students’ attitudes of classroom activities and includes the degree to which students appear to anticipate and view the activities as worthwhile, and the impact of activities on student interest, enjoyment, and understanding.

Data Management and Analysis

Computer software is a convenient tool to “speed up the processes of locating coded themes, grouping data together in categories, and comparing passages in transcripts or incidents from field notes” (Patton, 2002, p. 442). The qualitative software program Atlas.ti was used to facilitate the storing, coding, retrieving, comparing, and linking of data collected during this study. Once data was entered into Atlas.ti, a constant-comparison analysis was conducted as data collection occurred (Stauss & Corbin, 1990). Using Miles & Huberman’s (1984) components of data analysis flow model as illustrated in Figure 3, each piece of data informed subsequent data continuously through the case study in a data reduction process.
Data reduction analysis involves open coding method to identify themes and develop concepts that emerge from the data (Miles & Huberman, 1984). A start code used to code the data was generated from the CLEQ categories. The CLEQ categories that will be used as the start code with their associated characteristics are presented in Table 4.

Five of the six scales (PR, CV, SC, SN, and SA) were used to provide insight into teachers’ perception of their classroom learning environment before and after implementing a historical PBL approach. The SU scale was used to provide insight into changes in teacher perceptions regarding the use of historical perspective in PBL. The CLEQ scores for each scale were calculated according to the scoring guidelines in Appendix A for each participant before and after implementing a historical PBL. All six scales were graphed for each individual teacher for within-case analysis and for each scale with all participants for cross-case analysis. A ranking scheme was used to categorize each teacher’s agreement for each scale ranging from 7 to 35 points. A score of 7-13 indicated low agreement; a score of 14-20 indicated a low intermediate
agreement; a score of 21-27 indicated a high intermediate agreement, and a score of 28-35 indicated a high agreement.
<table>
<thead>
<tr>
<th>Categories of CLEQ</th>
<th>Associated Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  The classroom environment engages students in <strong>personal relevance (PR)</strong> by</td>
<td>▪ relating science to students; everyday interests and activities;</td>
</tr>
<tr>
<td></td>
<td>▪ developing students’ formal scientific knowledge through meaningful context of students’ everyday experiences.</td>
</tr>
<tr>
<td>2  The classroom environment engages students in <strong>scientific uncertainty (SU)</strong> by learning that scientific knowledge</td>
<td>▪ is evolving and provisional;</td>
</tr>
<tr>
<td></td>
<td>▪ is shaped by social and cultural influences;</td>
</tr>
<tr>
<td></td>
<td>▪ arises from human interests and values.</td>
</tr>
<tr>
<td>3  The classroom environment fosters students’ <strong>critical voice (CV)</strong> by creating a social climate in which students are free to</td>
<td>▪ question the teacher’s lessons and methods;</td>
</tr>
<tr>
<td></td>
<td>▪ express concerns about any obstacles to their learning.</td>
</tr>
<tr>
<td>4  The classroom environment invites students to <strong>share control (SC)</strong> of their learning by providing opportunities for students to</td>
<td>▪ design and manage their own learning activities;</td>
</tr>
<tr>
<td></td>
<td>▪ determine and apply assessment criteria;</td>
</tr>
<tr>
<td></td>
<td>▪ negotiate the social norms of the classroom.</td>
</tr>
<tr>
<td>5  The classroom environment should assist with <strong>student negotiation (SN)</strong> in which students interact verbally with other students to</td>
<td>▪ explain and justify their thoughts to each other;</td>
</tr>
<tr>
<td></td>
<td>▪ make sense of and reflect on the viability of other students’ ideas;</td>
</tr>
<tr>
<td></td>
<td>▪ critically reflect on the viability of their ideas.</td>
</tr>
<tr>
<td>6  The classroom environment positively impacts <strong>student attitude (SA)</strong> when</td>
<td>▪ students look forward to the learning activities;</td>
</tr>
<tr>
<td></td>
<td>▪ students sense that the activities are worthwhile;</td>
</tr>
<tr>
<td></td>
<td>▪ activities positively impact student interest, enjoyment, and understanding.</td>
</tr>
</tbody>
</table>

Research Quality

“The constructivist paradigm assumes a relativist ontology (there are multiple realities), a subjectivist epistemology (knower and respondent co-create understandings), and a naturalistic (in the natural world) set of methodological procedures” (Patton, 2005, p. 24). The criteria for judging the quality of qualitative interpretive case study include the important concepts of trustworthiness, credibility, confirmability, and data dependability (Yin, 2003). In social constructivist research, credibility is established through internal validity, transferability is established through external validity, dependability is established through reliability, and confirmability is established through objectivity.

This research study established construct validity by using multiple sources of evidence (CLEQ, interviews, field notes, and card sort activity) and by maintaining a chain of evidence during data collection. Internal validity was addressed during data analysis of multiple sources of evidence through pattern-matching, explanation-building, and addressing rival explanations. According to Merriam (1998), member checking is a strategy for increasing internal validity. She describes member checking as “taking data and tentative interpretations back to the people from whom they were derived and asking them if the results are plausible” (Merriam, 1998, p. 204) and points out that researchers can continuously member check during the study. As data reduction analysis was being completed throughout this study, participant feedback was solicited. Participants were asked to comment on interview transcripts and to explain responses made during the interview. After classroom observations, participants were asked to discuss their facilitation of the lesson and the field notes recorded during the lesson. Portions of the
final draft that were relevant to each participant were provided to participants to check for accuracy. To minimize the errors and biases of this study, reliability was addressed through using case study protocol and developing a case study database with Atlas.ti software to triangulate data collected (Yin, 2003).

Summary

This study was a qualitative interpretive case study of secondary science teachers’ perceptions of facilitating historical PBL lessons. The design, as depicted in Figure 2, included classroom learning environment questionnaires, individual interviews, a card sort activity, and participant observations. The four participants who took part in this study were experienced teachers having completed CERTL’s PBL workshop. The data was interpreted using the constant comparative method (Bogdan & Biklen, 2007) of inductive analysis. The questionnaires were the initial and final assessment of participants’ perceptions of their classroom learning environment during PBL instruction and were coded using Taylor et al.’s (1994) guidelines. Initial questionnaire responses provided initial data to assist with preparing for participant interviews. Individual interviews, both at the beginning and end of the study, were transcribed and imported into a database management system using Atlas.ti software and coded. While teachers provided historical PBL instruction in their classrooms, participant observations were conducted. Field notes recorded during participant observations were imported into the database management system and coded. Participants were asked to perform a card sort activity that involved categorizing and classifying major and minor successes, obstacles and limitations encountered while facilitating historical PBL lessons. This data was added
to the database and coded. The results were used to develop assertions regarding high school teachers’ facilitation of historical PBL instruction.
CHAPTER 4

RESULTS

Introduction

The purpose of this study was to explore high school science teachers’ perceptions and facilitation of their classroom learning environments during historical PBL instruction. More specifically, this study aimed to characterize teachers’ learning environments with respect to degree of alignment with constructivist principals. Constructivist principles encompass real-world problem solving, student ownership, inquiry, and reflection. Analysis of these principles in the CLEQ instrument included personal relevance, scientific uncertainty, critical voice, shared control, student negotiation, and student attitude. Another aim of this study was to identify teachers’ perceived obstacles and successes that were encountered in the classroom environment.

Prior to this study, participants completed the CERTL workshop where they learned a particular model for instructing PBL lessons. The model, detailed in Chapter 2, involved the following process:

1. Students read the problem
2. Students made a list of facts presented in the problem and what they need to know to solve the problem.
3. Students shared their list with the class.
4. Students researched what they need to know.
5. Students sometimes completed related activities.

For the current study, each participant taught the same historical PBL lesson on classification of kingdoms. The goal of the lesson was for students to understand how and why biologists classify living organisms by exploring, through the works of Copeland and Whittaker, the historical development of the six-kingdom classification system used by most biologists today. Since participants were trained during the workshop in using the CERTL problem blueprint planning form (see Appendix D), a blueprint that included required materials and details to teach the lesson was provided weeks before implementation. Participants were informed that they could modify the lesson; however, they were asked to teach the lesson historically using problems.

The first problem introduced to students to their role as a taxonomist in 1956 and presents Copeland’s four-kingdom classification scheme and Whittaker’s three-kingdom classification system. Copeland organized organisms according to evolutionary relationships, while Whittaker based his original system on an organism’s ecological role as producer, consumer, or decomposer. The second problem was set in 1957 after Whittaker immersed himself in the taxonomic literature of unicellular organisms and recognized that, similar to Copeland, he needed to add a fourth kingdom. While Whittaker used the same kingdom names (Plantae, Animalia, Fungi, and Protista), the organisms he placed in the Protista kingdom differed from Copeland. In the third problem, students discovered that by 1969 Whittaker became convinced that his Protista kingdom needed to be split into two separate kingdoms, Protista and Monera. The fourth and final problem explains to students Whittaker’s struggle with the conflicting demands of portraying a classification system that would reflect important ecological principles.
while still accurately portraying evolutionary relationships. Students are also introduced to Carl Woese and his 1977 ideas for a six-kingdom classification system.

The data analysis for this study was reported as individual case studies (Beth, Dana, Emma, and Mark) to include with-in case and cross-case results. The participants responded to interview questions and a classroom learning environment questionnaire, were observed implementing the PBL instructional unit, and classified successes and obstacles encountered during instruction.

Case Studies of Participants

In this section, a summary of each teacher and his or her school classroom environment is provided. The four teachers participating in this study worked in a semi-urban school district in a variety of settings; had a range of teaching experience, science background, and education; and taught a variety of subjects and levels. A summary of participants’ profiles is presented in Table 5. Participants and their schools were assigned pseudonyms to protect their anonymity. All participants taught in public schools in the same county in a southeastern state during the 2008-2009 academic year.

Beth / Nelson High School

Beth had a BS in Biology, secondary teacher certification in biology, and a M.A.Ed. in Biology Education. She was a teaching fellow at her undergraduate institution and, immediately after graduation, entered a graduate degree program. Upon completion of a Master’s degree in education, Beth accepted a teaching position at Nelson High School. Beth’s science experiences have all been academic, as she does not have any
practical experiences working as a scientist. At the time of this study, she was completing her fifth year of teaching. During those years, she taught both anatomy and physiology and biology.

Nelson High School served approximately 1,762 students, with a fairly even distribution of females (51%) and males (49%). The student ethnicity at Nelson High School was moderately diverse with 51% White; 40% Black; 6% Hispanic, and 3% Asian. The average number of students per section enrolled in biology was 22, and the average number of students who attended school daily was 94%. Approximately 23% of the student body was eligible for free or reduced lunch. During the 2007-2008 school year, 73% of the students scored at or above grade level in Biology. Being that 60 to

Table 5

**Participant Profiles**

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Highest Degree</th>
<th>Experience*</th>
<th>PBL Experience**</th>
<th>School***</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beth</td>
<td>M.A.Ed. in Science Education</td>
<td>5</td>
<td>N/P</td>
<td>NR</td>
<td>Regular (50-min.)</td>
</tr>
<tr>
<td>Dana</td>
<td>B.S. in Education</td>
<td>16</td>
<td>E</td>
<td>LP</td>
<td>Block (90-min.)</td>
</tr>
<tr>
<td>Emma</td>
<td>Ph.D. in Immunology</td>
<td>3</td>
<td>N/P</td>
<td>LP</td>
<td>Block (90-min.)</td>
</tr>
<tr>
<td>Mark</td>
<td>M.A.Ed. in physical Education</td>
<td>3</td>
<td>P</td>
<td>SD</td>
<td>Regular (50-min.)</td>
</tr>
</tbody>
</table>

* Experience: Number of years teaching including the 2008-2009 school year.
** PBL Experience: Participants’ self-described PBL experience level as N-novice, P-proficient, or E-expert.
*** School profile: As designated in 2009 by State School Performance Report Card. HSE-honor school of excellence, SE-School of Excellence, SD-School of distinction, SP-School of Progress, NR-no recognition, PS-priority school, and LP-low performing.
100% of students performed at grade level, Nelson High School joined 23% of the schools in the district in receiving a designation of no recognition.

Nelson high School was located off a quiet residential tree-lined street. The neighborhood surrounding the school consisted of middle-class single-family homes. Nelson was a one-story brick building with several classroom trailers located near the back of the school. Signs inside the main entrance to the school directed visitors to the main office where sign in sheets were located and visitor passes were obtained.

Beth was employed three-quarter time and taught two sections of biology and two sections of honors biology during the 2008-2009 school-year. Her classroom was located at the back southwest corner of the school near the faculty parking lot and bus loading/unloading zone. The room was an interior space and thus had no windows. Storage cabinets lined both sides of the room. A large whiteboard was mounted on the front wall directly behind the teacher’s desk and demonstration lab table. An overhead projector rested on a cart directly in front of the demonstration lab table. Student desks consisted of tables that seated two and were situated in rows that faced the front of the classroom.

When students entered Beth’s classroom, they knew the routine. Absent students picked up the previous days lesson from shelves to the right of the entrance door. Students needing homework help wrote the number of the homework problems needing to be explained on a dry-erase board hung on one of the walls. When the bell rang, students copied the essential question and define vocabulary words while Beth took attendance and completed administrative duties. Beth then checked students’ homework and answered their questions. Next, students either took notes on the day’s lesson or
listened to an explanation of the day’s activity. Students were then given a worksheet or asked to complete some activity. Class ended with students completing an exit ticket, which involved answering the day’s essential question and being given the night’s homework assignment.

*Dana / Carson High School*

Dana had secondary teacher certification in biology and a B.S. in Biology Education. Dana’s science experiences were limited to her undergraduate lab classes, as she does not have any practical experience working as a scientist. She graduated with honors and immediately accepted a science teaching position in the same school as her student teaching assignment for eight years. At the end of the eight years, Dana took five years off of teaching to raise a family. She has been teaching for the last eight years at Carson High School. In total, Dana had 16 years of experience teaching mostly prebiology, biology and honors anatomy.

Carson High School served approximately 870 students, with a fairly even distribution of females (49%) and males (51%). The student ethnicity at Carson High was primarily Black (69%; 24% White; 7% Hispanic, and >1% Other). The average number of students per section enrolled in biology was 15, and the average number of students who attended school daily was 90%. Approximately 53% of the student body was eligible for free or reduced lunch. During the 2007-2008 school year, 37% of the students scored at or above grade level in Biology. Since less than 50% of students performed at grade level, Carson High joined 39% of the schools in the district in receiving a designation of low performing.
Carson High School was located near the industrial part of town less than a mile from the local general aviation and flight training airport. The neighborhood surrounding the school consisted of low-end single and multi-family homes and apartments. Carson was a three-story brick building. A staff or parent volunteer, located on the first floor just inside the main entrance of the school, monitored the visitor sign in/out sheet.

Dana’s classroom was located one flight of stairs below the front entrance. Even though her room was located on the ground floor, the room was situated on the back side of the building which provided windows that looked out onto the steep grassy hill.

Because Carson was on a 90-minute block schedule, Dana taught three classes which included two sections of biology and one section of anatomy during the 2008-2009 school-year. Her classroom included two separate spaces. The space to the left of the entrance door was a small, unorganized space with high permanent laboratory tables where in the corner Dana kept a teacher desk and computer. The space to the right of the entrance door was larger and consisted of student tables that sat two situated in rows that face a large whiteboard mounted to the front of the room opposite the windows. On a bulletin board beside the whiteboard, Dana kept track of student progress (completing assignments and/or attending tutorial) toward being exempt from taking her final exam.

On the front wall beside the bulletin board was a poster explaining the seven norms of collaborative work.

When students entered Dana’s classroom, she immediately began giving instructions to copy the essential question from the board and recorded their attendance on her clipboard. High up on the side wall, Dana had posted her CHAMP (Conversation, Help, Activity, Movement, Participation) poster. The poster provided the structure and
organization of student behavior for different classroom learning activities. Dana strictly followed the structure listed for the type of learning event (i.e. tests, direct instruction, class-work, group work/lab) of the day’s lesson. The poster is color coordinated (i.e. red, orange, yellow, and green, respectively) so Dana would state the color zone that detailed the day’s expectations for behavior. Dana usually closed her day’s lesson with a repetitive recall of the lesson’s main point.

*Emma / Carson High School*

Emma had a BS in Biology and Education, lateral entry provisional secondary teacher certification in biology and chemistry, and a Ph.D. in Immunology. Upon completion of a doctorate, Emma worked in a research laboratory for 17 years providing her with practical experiences working as a scientist. She completed her teaching certification out of state and let her teaching license expire while working as a research scientist. At the time of this study, she was completing her third year of teaching. During those years, she taught prebiology, biology, honors biology, chemistry, and honors chemistry. When the 2008-2009 school year ended, Emma was eligible for a standard provisional license to teach biology and chemistry.

Like Dana, Emma taught at Carson High School, which was profiled in the above section. Emma’s classroom was located a few classrooms down from Dana. While their classrooms were located on the same side of the building, Emma’s room had smaller windows located higher up on the wall as her room was located more underground. Being on a 90-minute block schedule, Emma taught three classes during the 2008-2009 school-year which included two sections of biology and one section of chemistry. Her classroom included two separate spaces: a large, organized space with high permanent laboratory
tables for conducting chemistry experiments and a smaller space consisting of student
tables that sat two situated in groups. A small whiteboard mounted to the wall of the
room opposite the windows provided a space for Emma to give notes. On the side wall of
the small space, behind a cluttered demonstration laboratory table, was another small
whiteboard where Emma listed essential questions and homework assignments. Emma’s
teacher’s desk and computer were situated in the back corner of the small space area
adjacent to the demonstration laboratory table.

When students entered Emma’s classroom, they mingled and talked until the bell
rang. Emma typically began class by asking students how they were doing; to which none
of the students gave a response. Unlike the other participants, Emma did not have a
particular routine that she followed. She sometimes began with students correcting and
responding to test or homework questions, completing a worksheet or bookwork
assignment, taking notes as she lectured, or conducting a hands-on activity. At the end of
class, Emma had her students write an exit ticket that included something learned and
something that could have been better.

Mark / Westfield High School

Mark had a BS in Physical Education, secondary teacher certification in biology,
and a M.A.Ed. in Physical Education. After graduating with his Master’s degree, Mark
worked for a few years at an environmental education center before accepting a teaching
position as a long-term substitute at Westfield High School. The next year he passed the
Praxis exam to add-on biology to his license, and began teaching biology full time and
coaching sports at Westfield High School. Mark had the unique experience of working in
an informal science setting, but did not have any practical experiences working as a
scientist. At the time of this study, he was completing his third year of teaching biology, inclusion biology, and honors biology.

Westfield High School served approximately 1,943 students, with a fairly even distribution of females (49%) and males (51%). The student ethnicity at Westfield High was primarily White (73%; 15% Black; 7% Hispanic, 4% Asian, and >1% Other). The average number of students per section enrolled in biology was 20, and the average number of students who attended school daily was 95%. Approximately 12% of the student body was eligible for free or reduced lunch. During the 2007-2008 school year, 82% of the students scored at or above grade level in Biology. Since at least 80% of students performed at grade level, Westfield High School joined 15% of the schools in the district in receiving a designation as a school of distinction.

Westfield High School was located off a main divided highway less than one mile from a major interstate. The neighborhood surrounding the school consisted of mixed-use commercial developments and middle-class single-family homes. Westfield High School consisted of a series of one-story brick buildings connected with metal canopy covered sidewalks. The school was under construction to replace all of the trailers with brick buildings. Visitors were expected to sign in at the temporary office located in a brick building. Each discipline had its own separate building. The science building was located in one of the central buildings.

During the 2008-2009 school year, Mark taught one section of inclusion biology, two sections of biology, and two sections of honors biology. His classroom was located about half way down the newly constructed science building. The spacious room had large windows on the side facing the adjacent building. Because students used the
walkway along side the windows during lunch, Mark kept the blinds closed. Covering the flat screen television mounted to the corner wall was an interactive (Promethean) whiteboard connected to a portable projector and computer. The computer rested on the demonstration laboratory table situated adjacent to the Promethean board. Behind the demonstration laboratory table was a large whiteboard. Mark had two teacher desks on each side of the front of the classroom, but mostly used the demonstration laboratory table as his main desk. Student desks consisted of tables that seated two and were situated in rows that faced the front of the classroom.

When students entered the classroom, Mark immediately engaged them in small talk. He seemed genuinely interested in their lives outside of class. Shortly after the bell rang, students typically took out their notes packets, which were prepared and distributed at the beginning of the unit. Following this, Mark proceeded to engage students in the day’s topic by probing for their understanding. Students were then presented with a PowerPoint lecture while filling in the blanks in their notes packets. Since Mark had a dedicated classroom Promethean whiteboard, he interacted with the PowerPoint slides by enlarging and moving around images, highlighting text, and writing/drawing on the slides. Next, Mark facilitated an activity where students explored the topic further. Class ended with Mark discussing with students the day’s central ideas.

Within-Case Analyses

Presentation of within-case analysis for each teacher participant (Beth, Dana, Emma, and Mark) was arranged by the research questions. Each case was divided into three sections for each teacher. The first section presents the participant’s alignment of
instruction with constructivist principles. Participants’ CLEQ scores were categorized using a ranking scheme for each teacher’s agreement ranging from 7 to 35 points. A score of 7-13 indicated low agreement; a score of 14-20 indicated a low intermediate agreement; a score of 21-27 indicated a high intermediate agreement, and a score of 28-35 indicated a high agreement. The second section depicts the participant’s facilitation of the historical PBL. Descriptors used for student engagement included very low for 20% or fewer engaged students, low for 21-40% engaged students, moderate for 41-60% engaged students, high for 61-80% engaged students, and very high for 81-100% engaged students. Learning environment principles descriptors included not evident or negative, evident or neutral, and well represented or positive. Descriptors detailing learning direction involved how much control the student exercised (none, some, shared, most, or all) during learning. The third section portrays the participant’s successes, obstacles and limitations when facilitating the historical PBL lesson. Successes were defined as events of desired achievement, obstacles as events that interfered with or hindered learning, and limitations as events that restricted or weakened learning.

Beth

Alignment of Instruction with Constructivist Principles

Beth’s typical instruction was representative of a more discipline-based curriculum as opposed to a reform-based curriculum as explained in Table 1. She did not implement a constructivist learning environment on a regular basis. Her typical teaching strategies included note-taking, reproducible worksheets, bookwork, and traditional laboratory activities. In terms of PBL, Beth commented that she has not taught a PBL lesson since she has been teaching biology. Beth viewed PBL as an instructional strategy
for advanced students stating that “PBL goes way beyond what students need to know for 9th grade biology.” Beth understood PBL to be “very open ended and very free flowing and so it gives students a chance to kind of participate in their own knowledge seeking.” Regardless, Beth was concerned about student engagement during PBL instruction and was not convinced that a real-world problem would keep students focused. For Beth, the problem-solving aspect of PBL lessons should maintain student interests; however, she admitted being worried about keeping students focused throughout the historical PBL instructional unit.

Her classroom routine was organized and procedural and the classroom culture was one of mostly teacher-directed learning. Beth commented that

to a certain extent [student learning should be directed] by the students, but as the facilitator I need to be a puppet master and direct them that way…. For instance, I need to be very specific about what I want them to do and have things ready for them.

Sharing control of the learning environment so that students are directing the learning was problematic for Beth. Additionally, Beth mentioned that the open inquiry nature of PBL lessons is “sometimes where I have struggled.” Since there are specific answers that students need to know for the end of course test and not a lot of time to cover all the required material, Beth views PBL as a “tool to push kids beyond the standards that they need to study.”

Student reflection was low in priority for Beth. She stated,

I’m sure as it comes down to crunch time and getting through the PBL that [student-student discussion and reflection] might be what gets thrown out first, but it should be that I might cut down research before I cut down the chance for them to talk about and think about what everybody is reflecting on.
Keeping pace with the county mandated pacing guide took precedence throughout Beth’s instruction. During the post interview, Beth remarked that she gave students little time to discuss, as she needed to push on through the lesson to keep pace with the county’s guideline.

Beth’s reported PBL and historical PBL critical voice and student negotiation scores were 30/29 and 28/29, respectively. These scores were in the high agreement range, which indicated that she placed a high emphasis on encouraging students to question her plans and methods and express concerns about impediments to their learning and on providing opportunities for students to justify their thoughts to each other, make sense of other students’ ideas, and reflect on the viability of ideas. Her reported PBL and historical PBL scores for scientific uncertainty, shared control, and student attitude, respectively, were as follows: 23/24, 21/21, and 23/26. These high intermediate agreement scores suggest that she perceived both as often but not always emphasized science as evolving, provisional, and culturally shaped; invited students to participate in managing learning activities, determining assessment criteria, and negotiating classroom social norms; and felt students looked forward to the learning activities, found the activities worthwhile, and enjoyed and understood the activities. Her perceived personal relevance scores of 29 for PBL and 25 for historical PBL decreased from a high agreement to high intermediate agreement range. This indicated that Beth felt as though PBL lessons more often than the historical PBL lesson linked school science with students’ everyday experiences. Beth’s overall PBL and historical PBL instruction scores were both 26 indicating high intermediate agreement to constructivist principles. Beth’s CLEQ scores are exhibited in Figure 4.
Abbreviations: PR=personal relevance, SU=scientific uncertainty, CV=critical voice, SC=student choice, SN=student negotiation, and SA=student attitude

*Figure 4.* Beth’s CLEQ Scores

*Facilitation of Historical PBL*

Beth maintained most aspects of her normal classroom routine when facilitating the historical PBL instructional unit. She began each day as usual by checking and reviewing students’ homework. Then students filled in the blanks of a daily notes sheet during a power point presentation. In place of an activity that would typically follow giving notes, Beth substituted the PBL lesson sequence. The class ended with students being reminded of the night’s homework and being given a ticket out the door type activity, where students were asked to write three things they learned and two things they didn’t understand. All five days were similarly structured throughout the four problems that made up the historical PBL unit of instruction.

During the PBL lesson sequence, Beth followed the overall process taught in the CERTL workshop. However, prior to implementing each problem lesson sequence, she provided students with notes previously prepared for the topic. Beth also maintained the
same textbook readings and worksheets as homework assignments throughout the PBL lesson sequence. Neither the notes nor homework followed the historical nature of the PBL lesson; textbook readings assigned half-way through the series of problems gave students a textbook solution. An issue Beth mentioned was not modifying out-of-class assignments to coincide with the problems presented in the lesson. Students were able to prepare a diagram of the six kingdom classification system, but many students were not able to adequately explain why certain species were placed in certain kingdoms. Beth commented that she should “maybe do the PBL first … and then during the PBL spend more time focusing on Whittaker and Copeland.” Beth thought she might then give notes and bookwork assignments for a few days following teaching the PBL, but remained skeptical about how to do this in the limited time given to her by the county mandated pacing guide.

Aspects of Beth’s facilitation of the individual components differed from those advocated in the CERTL workshop and were less constructivist in nature. Figure 5 presents Beth’s constructivist classroom observation scores. Learning direction and constructivist principles followed similar trends during Beth’s facilitation of the lesson. Beth directed all learning when giving notes, directed most of the learning when students were reading, thinking and sharing, and shared learning direction with students during the research and activity portions. While observing Beth facilitate the lesson, constructivist principles were not evident when students were taking notes, but somewhat evident during other components of the PBL. Students exhibited low engagement when taking notes during the Power Point presentation, moderately high engagement during the
Figure 5. Beth’s Classroom Observation Scores

reading, thinking, and sharing portions of the lesson, and high engagement when researching solutions to the problem and completing an associated activity.

At the beginning of each day, Beth directed all learning from the front of the classroom. After having students copy notes on classification, she transitioned to providing students with the historical problem. When presenting the first problem, Beth remarked that the type of learning students were about to undertake would be new to them and she had not taught this way in a number of years. She stated, “it might be a little uncomfortable for you and will be a lot of work.” This introduction illuminates Beth’s lack of confidence and unease with students’ first exposure to PBL instruction. After introducing the problem, students worked without teacher assistance while Beth completed administrative work. She would call on students with raised hand and respond from the front of the classroom. After giving students about 10 minutes to identify facts in the problem and identify research questions, Beth announced for students to finish their task. She then directed most of the share portion of the PBL calling on one student
in each group to provide a response that she subsequently interpreted and wrote on the board. In each class observed, Beth unevenly assisted student learning during research and activities allowing some groups to manipulate her time more than others.

Beth missed opportunities to engage students in personal relevance. For the historical PBL, she relied solely on “telling them [students] a story and getting them hooked on something [learning]” thinking this to be “a good way to engage them in the six kingdoms and in classification.” The first problem asks students to play the role of a taxonomist throughout the PBL lesson; however, this role was not a main focus for Beth. Instead, she assigned cooperative learning roles (leader, secretary, researcher, and product) to students, and throughout the lesson, focused students on taking responsibility for their assigned role. At one point during the lesson, a student asked about being a taxonomist. Beth responded, “you could be a taxonomist, you have to know species, wish we had time to get into it.”

Constructivist learning environment principles were somewhat evident, but not well represented, during the PBL lesson components. Beth acknowledged, “Sometimes I know I’m controlling so I don’t, maybe I could have been more open ended.” Prior to starting the PBL, she purposefully grouped students based on past performance and personality, and directed them to different tables as they first entered the classroom. Beth randomly assigned cooperative learning roles based on student birthday. The leader read the problem and shared responses with the class, the secretary took notes, the researcher manipulated the resources provided, and the product person put together group assignments. Students were not given a choice in managing the learning environment. When leading students in sharing information, Beth recorded student responses on the
board for the secretary of each group to include in their group’s notes. Students were not given the opportunity to discuss or negotiate responses as advocated in the CERTL workshop. Beth stated, “…I gave them [students] little time to discuss.” Students were given activities to complete during the PBL, which were application in nature. When facilitating activity and research experiences, Beth would guide students to a correct answer by asking lower order (yes/no and either/or) cognitive questions.

**Successes, Obstacles and Limitations when Facilitating Historical PBL lesson**

During the card sort activity, Beth identified ten successes, five obstacles and three limitations when teaching the historical PBL instructional unit. Table 6 presents the results of Beth’s card sort activity. Beth categorized most of the successes as student learning and instructional design. She ranked students’ active participation and ability to work through the problem as most successful. Other successes Beth identified when teaching the historical PBL were categorized as instructional design and included student NOS understandings, final assessment products, higher order thinking, and to a lesser degree instructional time and research resources. Specifically, Beth commented that students had an understanding of how science changes over time and that science needs evidence. When asked what view of science PBL lessons help to promote, Beth stated that science is collaborative, findings needs to be shared and critiqued, and ideas build on previous information. She also mentioned that students’ reaction was a success stating how students conveyed that the lesson was “fun” and that she “found them really engaged.” Beth was pleased with how students performed on the assessment products remarking, “they [students] did a very nice job.”
Table 6

Beth’s Categorization of Successes, Obstacles, and Limitations

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Category</th>
<th>Rating/Order</th>
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<td>M-1</td>
</tr>
<tr>
<td>Success</td>
<td>Identifying facts/questions</td>
<td>SL</td>
<td>M-2</td>
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<td>Success</td>
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<td>SL</td>
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<td>Success</td>
<td>NOS understanding</td>
<td>HID</td>
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<td>Success</td>
<td>Assessment product</td>
<td>ID</td>
<td>M-5</td>
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<td>Success</td>
<td>Higher order thinking</td>
<td>ID</td>
<td>M-6</td>
</tr>
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<td>Success</td>
<td>Assigning jobs</td>
<td>TE</td>
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<td>ID</td>
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<td>Success</td>
<td>Helpful resources</td>
<td>ID</td>
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<td>MID</td>
<td>m-10</td>
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<td>Required weekly quizzes</td>
<td>SA</td>
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<td>Limitation</td>
<td>Pacing Guide / SCOS</td>
<td>SA</td>
<td>m-2</td>
</tr>
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<td>Limitation</td>
<td>Uncooperative groups</td>
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<td>End of course test</td>
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<td>Obstacle</td>
<td>Including book work</td>
<td>MID</td>
<td>m-5</td>
</tr>
<tr>
<td>Obstacle</td>
<td>Naive student reflections</td>
<td>ID</td>
<td>m-6</td>
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<td>Obstacle</td>
<td>Introducing the PBL</td>
<td>MID</td>
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<tr>
<td>Obstacle</td>
<td>Lack of specifics</td>
<td>ID</td>
<td>m-8</td>
</tr>
</tbody>
</table>

Abbreviations: ID=Instructional design; HID=Historical instructional design; SL=student learning; SA=school administration; MID=Modified instructional design; TE=teacher experience; M=major; m=minor

Beth viewed all obstacles and limitations as minor and ranked the limitations higher than the obstacles; most categorized as school administration. According to Beth, the science department’s weekly quizzes, county mandated pacing guide, and end of course test limited her flexibility in implementing PBL. She viewed group dynamics as an overall minor limitation having two students uncooperative in their group. Other minor instructional design obstacles Beth identified centered around modifying the PBL to her established classroom culture considering PBL to be “a very uncomfortable way of learning for some students especially just doing one and then going back to regular
classroom stuff.” At the end of the post-interview, Beth mentioned that she planned on teaching the lesson again with a few modifications.

Dana

Alignment of Instruction with Constructivist Principles

Dana’s typical instruction was representative of a more reform-based curriculum. She routinely implemented a constructivist learning environment commenting that she typically taught 6 PBL lessons during the biology course. Dana viewed PBL as an instructional strategy for all students stating that PBL helps students to learn that “there are lots of right answers, and still wrong answers, but lots of right possibilities.” Dana understood PBL to be “presenting the problem [to students] and expecting them to use the resources you’ve given them to solve it and to take care of it.” Dana placed a high degree of importance on using real-world problems that will interest students. Being realistic, Dana remarked that

Since every problem can’t interest every child, you try to hit in the teenage realm of their interest. A lot of the time you go with careers because all kids are thinking about what they want to be when they grow up… You get to know your kids… So you know if [the problem] is going to spark [students] interest at least at some point.

For Dana, the problem aspect of PBL lessons should engage students and be open-ended to include more than one right answer. Working around the county mandated pacing guide could be difficult. Dana remarked,

The worst part about bringing it [PBL] into the classroom is matching that pacing guide. Knowing that pacing guide is sitting there whether you take three days to do the PBL or not. So learning how to work the PBL around the pacing guide has been the most challenging, the part I’ve had to work on the most.
Dana’s classroom routine was organized and procedural, and the classroom culture was one of shared student-directed learning. Dana commented that once given the problem, students take ownership over the path taken to solve the problem; however, students need to be “geared in the right direction. You still have to get them to learn by the end of the day, but the direction they take may still be different.” Dana has found allowing students to go on divergent paths to be personally challenging.

Student discussion and reflection was an important aspect of PBL for Dana. She stated,

You have to [have student-student discussions]. You can’t work with a group of people and make decisions if you’re not reflecting and discussing. Mine [classroom] are arranged so I can do PBL or a lab, so they [students] are in groups of 4…that’s their team.

During the majority of the PBL, students worked collaboratively on the problem, which provided them with opportunities for discussion. The expectation Dana established was for students to be able to explain or justify their thinking.

Dana’s reported PBL and historical PBL personal relevance, scientific uncertainty, critical voice, and student negotiation scores were 34/34, 29/30, 35/35 and 35/35, respectively. These scores were in the high agreement range, which indicated that indicating that Dana felt as though both lessons linked school science with students’ everyday experiences; perceived both as emphasizing science as evolving, provisional, and culturally shaped; placed a high emphasis on encouraging students to question her plans and methods and express concerns about impediments to their learning during both lessons; and placed a high emphasis on providing opportunities for students to justify their thoughts to each other, make sense of other students’ ideas, and reflect on the viability of ideas. Her reported PBL and historical PBL scores for shared control and
student attitude, respectively, were 27/29, and 27/31. These high intermediate agreement scores suggest that she perceived her historical PBL lesson as more inviting of students to participate in managing learning activities, determining assessment criteria, and negotiating classroom social norms than her PBL lessons and felt students more often looked forward to the learning activities, found the activities worthwhile, and enjoyed and understood the activities of the historical PBL instructional unit. Dana’s overall PBL and historical PBL instruction scores were both 31 and 33, respectively, indicating high intermediate agreement to constructivist principles. Dana’s CLEQ scores are exhibited in Figure 6.

Abbreviations: PR=personal relevance, SU=scientific uncertainty, CV=critical voice, SC=student choice, SN=student negotiation, and SA=student attitude

**Figure 6.** Dana’s CLEQ Scores

**Facilitation of Historical PBL**

Dana, having fully embraced and implemented PBL instruction for years, taught with a style that incorporated a classroom routine that corresponded well for facilitating the historical PBL lesson. The green zone (group work/lab) of her CHAMP management
system provided structure for students. Expectations of students included conversing on topic and in their group only, seeking help when the teacher was in close proximity, completing the activity as assigned, moving as needed for the assignment, and participating actively within their group. Each day began with Dana conducting a brief, five-minutes or less, introduction where she would conduct a focus review and highlight the day’s learning outcomes. This was followed by conceptual development where she scaffolded students through the PBL process. For most of the lesson, students worked collaboratively in small groups while Dana circulated the room giving short term assistance, support, and encouragement when needed. Finally, the class ended with Dana conducting a short recall closure intended to be a review of the lesson’s key points.

Dana began the PBL lesson sequence by introducing the problem to students and giving them a typed resource packet with hand written comments and underlined words throughout. In their group, students recorded key terms and definitions. While students would typically identify and research unfamiliar terms during the PBL, Dana felt that her students would become frustrated and “shut down” without having this initial exposure that they could later reference. Dana modified the lesson to explicitly emphasize classification more and as a result NOS became less prevalent. On one day, she inserted a short, approximately 10-minute, mini-lecture using the orange (direct instruction) CHAMP zone in which she used a grocery store analogy to explain how to sort or classify items. At the end of the lesson, Dana was confident that students could see how science changes over time and understood key terms that might be helpful for the end of course test. Dana commented that she would teach the lesson again with more focus on
the historical development of classification if she could cover the “stuff they [students] need to know” as identified in “the all important pacing guide.”

Dana exemplified the facilitation of the individual PBL components advocated in the CERTL workshop. Figure 7 presents Dana’s constructivist classroom observation scores. All three measures (learning direction, student engagement and constructivist principles) showed similar trends. For most of the lesson, Dana shared the direction of student learning with students. She directed slightly more of the lesson during the first component where students used teacher provided resources to take notes on key terms and slightly less of the lesson when students shared their information with the class. Student engagement followed a similar pattern to learning direction; students exhibited moderate engagement when identifying key terms, high engagement during the sharing component, and moderately high engagement during the other components of the lesson. Constructivist principles were well represented during the share component and evident,

![Figure 7. Dana’s Classroom Observation Scores](image.png)
but not well represented, through other components of the PBL lesson. Dana did not
conduct an associated activity during the PBL; therefore, that component was not scored.

One of the aspects of the CERTL PBL workshop Dana adopted completely was
student ownership of learning. She spent each day of the PBL walking between groups
thus constantly varying her proximity and being available for student questions. Dana
carried with her a clipboard and paper for taking attendance, recording notes, and
formatively assessing student understanding. For about 10 to 15 minutes at the beginning
of each problem, Dana gave little assistance as she walked around the room. She would
smile, give encouragement and state that she would be back to answer just one question.
Dana commented “Sometimes I find that when I go back over there, they [students] go
we got it while you were gone. That’s the goal.” When circling the room and helping
individual groups, Dana spent short amounts of time with each group not allowing any
one group to dominate her time. When asked how she facilitated a good flow between
groups, Dana remarked,

You have to honor and answer that first question, if they have another one
you go ok you guys think through that one. You have to get around to
other groups. If you stand there forever you’re going to answer every
question they have and then they’re not doing anything. So they realize
that I’m not going to answer every question they have that they’ve got to
think.

By giving students merely enough help to “push through so that they don’t get too
frustrated and give up,” Dana shared the direction of learning with students while
encouraging student ownership of their learning.

As students directed more of their learning, student engagement increased.
According to Dana, high student engagement was related to their motivation to solve the
problem by organizing organisms on their own in different ways. Dana used a few
techniques to help students stay focused on learning. She gave time limits with
reminders, was specific about expectations, and continuously moved around the
classroom. At different times during the PBL, Dana used the role of students as
taxonomist to engage students through personal relevance. The lesson was introduced
with students playing the role of a taxonomist. Later in the lesson, students were asked to
compare their organism classifications to the two taxonomists in the PBL. Dana tolerated
some off-task behavior and worked patiently to get students refocused on learning by
increasing her proximity to off-task students, questioning off-task students about their
work, or providing new information to keep groups challenged with the problem.

Constructivist learning environment principles were evident during Dana’s
facilitation of the PBL lesson components. Dana established a good rapport and trust with
her students allowing for students to share control of the learning environment. Students
self-selected into cooperative groups and worked collaboratively on the PBL. When an
absent student returned to class, fellow group members explained the material missed.
Student negotiation for this PBL occurred mostly during small group and a few times
with the whole class. Dana remarked, “I didn’t think this PBL centered on let’s all stop
and talk about where we are. Sometimes it’s good to stop and talk about where you are,
but this time it’s not. I didn’t feel like it.” Her formative assessment of student
understanding led her to conclude that students were progressing well through the PBL in
small groups and that whole class discussion was not necessary. The combination of
Dana’s circulating around the classroom and formative assessment provided Dana with
observational data helpful with facilitating student learning. Her formative assessment
helped her to know when to provide a short mini-lecture. When asked how she knew when to provide groups with assistance, she commented,

Look at their faces. Look at how they’re interacting with each other and you know they quit [stopped working on the task]. That’s the group you need to go to next. You can’t be at all groups at one time, so you have to read their body language, and it’s not something you can explain because it’s something a teacher knows.

Successes, Obstacles and Limitations when Facilitating Historical PBL lesson

Dana identified six successes, three obstacles and four limitations while teaching the historical PBL instructional unit. The results of Dana’s card sort activity are presented in Table 7. Dana categorized the successes as student learning and instructional design. She ranked students’ ability to negotiate the problem as the most successful followed by the lesson’s encouragement of higher order thinking and assessment product. Dana ranked higher order thinking as high because “students knew the difficulty of designing dichotomous keys.” Other successes identified when teaching the historical PBL included students’ active participation, ability to work through the problem and organize the picture resources provided. Dana remarked, “students participated who usually did not” and “they liked using the pictures.”

Dana categorized obstacles and limitations as school administration, student learning and instructional design. Dana saw administrative support as a must for successful implementation of PBL commenting, “administrator’s need to be OK with noise.” An incident between two students outside the classroom caused some difficulty forcing Dana to limit her movement when one of the students returned to class. She felt that administrators could have done more to reconcile the issue prior to re-admitting the student. Students at the school were assigned to three different biology classes depending
on their predetermined ability level, and Dana thought that this limited students learning from each other during the PBL. Dana labeled as a minor limitation the county mandated pacing guide, which did not allow for enough time to adequately implement PBL lessons.

According to Dana, student learning and instructional design caused some obstacles. Dana commented that a couple of apathetic students lacked motivation regardless of the PBL approach. She also noted that some students lacked continuous focus which was normal for these learners. Another obstacle to instructional design was instructional time. Dana found it challenging to narrow down the PBL to be “doable for students in the short period of time allotted in the pacing guide.” At the end of the post-interview, Dana mentioned making a few rewrites and teaching the lesson “a little bit differently next year.”

Table 7

*Dana’s Categorization of Successes, Obstacles, and Limitations*

<table>
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<th>Type</th>
<th>Description</th>
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<tr>
<td>Success</td>
<td>Higher order thinking</td>
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<td>ID</td>
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<td>Active participation</td>
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<td>Success</td>
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Abbreviations: ID=Instructional design; HID=Historical instructional design; SL=student learning; SA=school administration; MID=Modified instructional design; TE=teacher experience; M=major; m=minor
Dana omitted NOS understandings from her card sort activity. During the pre-interview, Dana was asked what view of science PBL lessons help to promote. She responded with the idea the science does not “always provide a solid concrete single answer that works for everything,” and went on to elaborate that there can be lots of right answers and still wrong answers. However, she did not list NOS as a success, obstacle, or limitation of the PBL instructional unit.

*Emma*

*Alignment of Instruction with Constructivist Principles*

Emma’s typical instruction was representative of a discipline-based curriculum seldom implementing a constructivist learning environment. As a result of end of course testing, she commented that she only taught one or two PBL lessons per year in her biology course. Emma stated that she let herself

…be convinced by the general climate and working with people here [Carson High School] that it takes too long to do PBL….The pacing guide has a strong influence. We try to stick to the basic guide especially in biology….The biology [end of course] test is kind of more important [in biology than in other subjects] because the kids now have to pass the test to get out of high school.

Emma understood PBL to be about “creating a scenario that students can actually imagine themselves in.” She thought that “if the situation they [students] are put into is relevant, if they can relate, then it [PBL] can be very engaging for them.” For Emma, a real-world problem involved creating a scenario that placed students in a situation just out of high school. Emma admits not being confident with instructing PBL lessons feeling a “need to be more in control.”

Her classroom routine lacked organization, procedures, and consistency and exhibited a classroom culture of mostly teacher-directed learning. Emma remarked, “In
most of our lessons, we just tell them what they need to know and practice using that information.” When asked who decides the direction of learning, Emma commented how “ideally the students would be using the information that they research in the PBL lesson to determine the end product or what they get out of it.” While Emma seemed to grasp the essence of PBL’s emphasis on student-directed learning, she readily admitted not being comfortable giving students that much responsibility over their learning. Thus, sharing control of the learning environment by providing students with choices was challenging for Emma. She remarked that in spite of “reading a lot in a behavior workshop about how choices are good for students. I have personally not had many choices in my classroom.”

Emma views student discussion and reflection as something that naturally occurs when students “work in groups and they have to at least in pairs come up with their answers” and give presentations. She also remarked “I’m not encouraging that [student-student discussion] as much as I should be.” During the majority of the PBL, students worked in pairs or small groups on the problem, but mostly students took turns making decisions and little discussion and reflection between students was observed.

Emma’s reported PBL and historical PBL critical voice scores were 24 and 33, respectively. These scores represent an increase from high intermediate to high agreement which indicate that she placed a higher emphasis on encouraging students to question her plans and methods and express concerns about impediments to their learning during the historical PLB lesson. Her reported PBL and historical PBL scores for personal relevance were 23 and 22, respectively, indicating that she felt as though her PBL lessons and the historical PBL lesson linked school science with students’ everyday
experiences. Emma’s perceived PBL and historical PBL scientific uncertainty and student negotiation scores, 16/25 and 20/24, respectively, increased from the low intermediate to the high intermediate agreement range. These scores suggest that she perceived the historical PBL as more often than the PBL lessons as emphasizing science as evolving, provisional, and culturally shaped and placing a higher emphasis on providing opportunities for students to justify their thoughts to each other, make sense of other students’ ideas, and reflect on the viability of ideas. Her perceived student attitude scores of 21 for PBL and 20 for historical PBL showed a slight decrease from a high intermediate to low intermediate agreement range. This indicated that Emma felt students sometimes but not always looked forward to the learning activities, found the activities worthwhile, and enjoyed and understood the activities. Emma reported PBL and historical PBL shared control scores as 17 and 20, respectively. These low intermediate agreement scores suggest that lessons sometimes but not often invited students to participate in managing learning activities, determining assessment criteria, and negotiating classroom social norms. Emma’s overall PBL and historical PBL instruction scores were 21 and 24, respectively, indicating an increase from low intermediate to high intermediate agreement to constructivist principles. Emma’s CLEQ scores are exhibited in Figure 8.

Facilitation of Historical PBL

Emma did not appear to have a noticeable consistent classroom routine. She began most days engaging in power struggles with students. On one day shortly after the bell to begin class rang, Emma noticed that students were eating and told students to put the food away. When students did not comply, she exchanged words with three students
until ultimately sending them to in-school suspension. On another day, the struggle was over insisting that students move to a different table. Each day seemed to be a challenge for Emma to group students and start the lesson as her rapport with students was strained. Eventually, Emma would begin teaching the lesson regardless of students’ uncooperative nature. After providing students with some overall direction, she would visit each group to provide additional assistance. A few minutes before the end of class, students would begin to pack up their belongings and wait for the bell to end class. Emma spent more time trying to discipline students than she did presenting the lesson. This power struggle with students and the discipline problems that ensued impacted her ability to engage students in the PBL lesson. The lack of a classroom routine was a factor in students’ inability to settle into the lesson.

Having co-planned the PBL lesson with Dana, Emma followed a similar sequence. After introducing the problem to students, she handed out a typed resource
packet with handwritten comments and underlined words throughout for students to record key terms and definitions. Emma divided her time teaching the lesson between dealing with classroom management issues, working at her desk, and interacting with student groups. Emma acknowledged having classroom management issues that interfered with her ability to teach. Once students were working in small groups, which could take up to 20 minutes to orchestrate, Emma would periodically work at her desk on the computer taking attendance, checking e-mail, printing announcements, etc. A few times she closed the lesson by asking students to write something they liked about the day and what they would do to improve their learning. Emma has a CHAMP poster on her wall, but did not refer to the poster during the lesson and stated, “I have my CHAMP poster, but I don’t use it as effectively as others.” By the end of the lesson, Emma commented that her assessment indicated that students “appreciated what the scientists went through…and they learned about the specific aspects of living things.” While Emma liked the idea of incorporating historical evidence, she remarked,

We don’t talk about competing ideas so much…It’s not encouraged because it’s not in the standard course of study in most cases. Understanding that science changes is actually in the standard course of study so classification was a very good case for us to spend the time on because it can help them, hopefully, be successful on the EOC [end of course test]. But, it’s really not encouraged. I mean they encourage us to work miracles and teach the kids to think and teach them the content and all that, but at the end it’s like you need to know all these words and how to think about them.

Emma struggled with using reform-based practices as advocated in the CERTL workshop and with incorporating aspects of science not explicit in the SCOS. Figure 9 presents Emma’s constructivist classroom observation scores. Learning direction and
constructivist principles followed similar trends during Emma’s facilitation of the lesson. She directed most of the lesson during the first component where students used teacher provided resources to take notes on key terms and somewhat shared the direction of learning with students during the other components. Constructivist principles were not evident when students were taking notes, somewhat evident during the reading, thinking, and sharing portions of the lesson, and evident, but not well represented, during the research component. Students exhibited very low to moderately low engagement during most of the PBL which peaked when students were identifying facts and questions to research. Emma did not conduct an associated activity during the PBL; therefore, that component was not scored.

Emma provided students with an opportunity to take partial ownership of their learning, and about half of her students accepted this responsibility. She provided students with task instructions and let them work in their groups for about 10 minutes.
while she tended to other duties. One or two students would take the lead and do most of the work on the assignment. Emma thought students directed the learning “because they have a lot of freedom.” While students were working on the PBL lesson, Emma guided students by asking them questions, and thus shared the direction of students’ learning. Emma unevenly distributed her time between groups providing some groups with more attention than others.

While student engagement was typically low to moderately low, individual student engagement varied during the PBL. Two students exhibited high engagement during the entire PBL; however, at any one time the number of students actively engaged in learning did not exceed 40% of the class. Several students exhibited moderate engagement when Emma would visit their small group, but they did not sustain that level of active engagement in the lesson at other times. To better engage students, she tried to use personal relevance by reinforcing the role the PBL placed students in telling them, “Well you’ve got this deadline remember. You want to impress your new boss.” Other students, with whom Emma had a strained student-teacher relationship, exhibited a low to moderate level of engagement until Emma visited their small group at which time their level of engagement decreased. Additionally, one student was not engaged during the entire PBL lesson; he sat in a chair with his head on the desk the entire week. When asked about the student, Emma blamed the administration for the student’s lack of participation stating that he had issues and, in her opinion, had given up on school. She went on to explain that both social and cognitive complexities compelled administrators to switch the student between three different biology teachers during the school year.
Constructivist learning environment principles were somewhat evident, but not well represented, during the PBL lesson components. Emma thought that since the PBL provided students with choices, students were in control of the learning environment. However, Emma tried to control other aspects of the learning environment. She assigned student groups, organized where students should sit on different days, and directed most aspects of the learning environment. One constructivist principle well represented was students’ expression of critical voice. Most of the time students voiced their disdain for Emma commenting that she did not know how to teach rather than expressing views on how they learn best. A few days into the PBL, some students remarked that they “liked working in groups instead of copying notes.” Not having much opportunity to develop cooperative learning skills, student negotiating was challenging for some groups. Emma thought that in general students did well negotiating the problem in groups because there were not any quarrels.

Successes, Obstacles and Limitations when Facilitating Historical PBL lesson

During the card sort activity, Emma identified five successes, five obstacles and four limitations when teaching the historical PBL instructional unit. Table 8 presents the results of Emma’s card sort activity. Emma categorized the successes as student learning and instructional design. She ranked thoughtful discussions and higher order thinking and student enjoyment as major successes. Minor successes Emma identified when teaching the historical PBL were active student participation and personal relevance of students working as taxonomists. Emma commented that students engaged in thoughtful conversation and grasped the complexity of classifying living organisms. Also, most
Table 8

*Emma’s Categorization of Successes, Obstacles, and Limitations*

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Category</th>
<th>Rating/Order</th>
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<td>Thoughtful discussion</td>
<td>ID</td>
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<td>Success</td>
<td>Higher order thinking</td>
<td>ID</td>
<td>M-2</td>
</tr>
<tr>
<td>Success</td>
<td>Student Enjoyment</td>
<td>SL</td>
<td>M-3</td>
</tr>
<tr>
<td>Success</td>
<td>Active participation</td>
<td>SL</td>
<td>m-4</td>
</tr>
<tr>
<td>Success</td>
<td>Personal relevance of role</td>
<td>ID</td>
<td>m-5</td>
</tr>
<tr>
<td>Limitation</td>
<td>Social dynamics</td>
<td>SA</td>
<td>m-1</td>
</tr>
<tr>
<td>Limitation</td>
<td>Administrative support</td>
<td>SA</td>
<td>m-2</td>
</tr>
<tr>
<td>Obstacle</td>
<td>Lack of motivation</td>
<td>SL</td>
<td>m-3</td>
</tr>
<tr>
<td>Obstacle</td>
<td>Lack of preparation</td>
<td>TE</td>
<td>m-4</td>
</tr>
<tr>
<td>Obstacle</td>
<td>Lack of collaborative culture</td>
<td>TE</td>
<td>m-5</td>
</tr>
<tr>
<td>Obstacle</td>
<td>Questioning technique</td>
<td>SL</td>
<td>m-6</td>
</tr>
<tr>
<td>Limitation</td>
<td>Pacing Guide / SCOS</td>
<td>SA</td>
<td>m-7</td>
</tr>
<tr>
<td>Limitation</td>
<td>Different types of learning</td>
<td>ID</td>
<td>m-8</td>
</tr>
<tr>
<td>Limitation</td>
<td>Lack of ability</td>
<td>SL</td>
<td>m-9</td>
</tr>
</tbody>
</table>

Abbreviations: ID=Instructional design; HID=Historical instructional design; SL=student learning; SA=school administration; MID=Modified instructional design; TE=teacher experience; M=major; m=minor

students were more motivated working in groups in this PBL than doing bookwork.

Emma also mentioned that students used the role of taxonomist to motivate each other.

Emma viewed all obstacles and limitations as minor categorizing the most important limitations as school administration and other limitations as instructional design and student learning. Emma believed she and her students did not have the support of school administration citing her lack of backing in dealing with “a difficult mix of students in one period” and her students “giving up and deciding not to try because they do not have support to get an education.” Additionally, Emma noted that there was not enough time to fit PBL into the county pacing guide, some students simply prefer bookwork with right and wrong answers. She also thought that PBL required students to have writing skills beyond their ability level. Emma categorized the obstacles she
encountered while teaching the historical PBL as teacher experience or student learning. She admitted having “not fostered a culture that encourages students to work well together” and not being as prepared to teach the lesson as she should have been. Some students’ lack of desire to learn and Emma’s questioning students during the lesson contributed as obstacles to her facilitating PBL instruction.

Emma excluded NOS understandings from her card sort activity. During the pre-interview Emma was asked to provide her thoughts on what view of science PBL lessons help to promote. She responded with the idea that there can be more than one right answer, many ways to interpret science, and it’s important to defend scientific ideas. While she expressed the potential of PBL to promote NOS views, Emma did not list NOS as a success, obstacle, or limitation of the PBL instructional unit.

Mark

Alignment of Instruction with Constructivist Principles

Mark’s typical instruction was representative of a combined discipline-based with reform-based curriculum. He regularly implemented aspects of a constructivist learning environment into his lessons. When asked how often he used PBL in his courses, Mark commented that

In traditional terms, going through all the steps as I’ve learned them going through the CERTL course, probably three times during the whole year, but I’ve used elements of different ones that I was exposed to or simply some of the ideas that are in PBL.

Mark viewed PBL as an instructional strategy helping all students become “more responsible for their own learning.” He taught using PBL in his honors, regular, and inclusion biology courses. Mark understood PBL to engage students by providing “relevant scenarios, something they tie to real life situations and their imagination by
putting themselves in the shoes of a person that they’re not. Wanting to find the information for themselves.” For Mark, the real-world aspect of PBL lessons meant providing problems that students would find relevant. His concern with teaching PBL involved dedicating the time needed and still covering the required material stating, “The time issue is my biggest complaint as far as it goes with our pacing guide and having quarter tests and trying to squeeze information in.”

Mark’s classroom routine was organized and procedural and the classroom culture was one of partially student-directed learning. He remarked that the direction of student-learning is decided “by the students, by the directions decided by their interests, it’s decided by their abilities, decided by their dynamics, how they are able to contribute.” Mark embraced students’ taking ownership of their learning and willingly shared control of the learning environment with students. When possible, he allows for flexibility for students to “go in different directions…and come up with different final products.”

Student-student discussion and reflection was a priority for Mark. He commented, it’s one of those pieces of PBL that I’ve pulled out more independently for a lot of different things. For a lab report students do, I’ll have them work on it together, give it to another group to make some comments on and give it back to them and let them make some corrections based on the comments from their peers.

Throughout the PBL lesson, students were observed discussing, debating, and reflecting in small group and as a whole class.

Mark’s reported PBL and historical PBL personal relevance, scientific uncertainty, and critical voice scores were 22/25, 23/24 and 26/25, respectively. These scores were in the high intermediate agreement range, which indicate that he felt as though his PBL and historical PBL lesson often but not always linked school science with
students’ everyday experiences; perceived both as often but not always emphasizing science as evolving, provisional, and culturally shaped; and that he often placed a high emphasis on encouraging students to question his plans and methods and express concerns about impediments to their learning during both lessons. His reported PBL and historical PBL student negotiation and student attitude scores, 20/23 and 19/27, respectively, increased from low intermediate to high intermediate agreement. These scores suggest that he perceived as the historical PBL lessons as more often than the PBL lesson as placing a higher emphasis on providing opportunities for students to justify their thoughts to each other, make sense of other students’ ideas, and reflect on the viability of ideas. Also, students more often looked forward to the learning activities, found the activities worthwhile, and enjoyed and understood the historical PBL instructional unit. Mark reported PBL and historical PBL shared control scores as 15 and 18, respectively. These low intermediate agreement scores suggest that lesson sometimes but not often invited students to participate in managing learning activities, determining assessment criteria, and negotiating classroom social norms. Mark’s overall PBL and historical PBL instruction scores were 20 and 23, respectively, indicating an increase from low intermediate to high intermediate agreement to constructivist principles. Mark’s CLEQ scores are exhibited in Figure 10.

Mark’s Facilitation of Historical PBL

Mark, having incorporated aspects of PBL from the CERTL workshop into his teaching repertoire, maintained a classroom routine compatible for facilitating the historical PBL instructional unit. He spent the first five minutes of class time with students facilitating a conversation about extracurricular activities. Students would
Abbreviations: PR=personal relevance, SU=scientific uncertainty, CV=critical voice, SC=student choice, SN=student negotiation, and SA=student attitude

**Figure 10.** Mark’s CLEQ Scores

mentioned how they performed in a sporting event or what their after-school club was doing. Mark then facilitated a dynamic lecture by engaging students while using the Promethean whiteboard, which enabled him to interact with the lecture slides by enlarging images, write and highlight text. He maintained students’ attention by asking open-ended questions and connecting the material to their interests. After the approximately 15 to 20 minute lecture, he smoothly transitioned students into the PBL sequence. At the close of the lesson, he held a short recap of the day, which often included students sharing what they learned. Mark similarly structured the historical PBL unit of instruction throughout the four problems.

Before implementing each problem lesson sequence, Mark conducted a lecture where students filled in blanks on their notes packet. The notes presented to students followed the historical nature of the PBL lesson. For example, on the day students would be researching about fungi, Mark gave students information about fungi. He also
correlated activities during the PBL sequence such as setting up microscopes with fungi around the room for students to make observations. At the end of the lesson, Mark thought students had a good understanding of classification and the scientific process. Thinking students would become restless because his previous PBL lessons typically last no longer than a couple of days, Mark commented that the historical approach provided continuity over a whole week…. I think it was healthy for them to take ownership over something that long….PBL that follow a story lines is a strength, I’d say, definitely. It provides opportunities for students to think like scientists back then, to understand how we got where we are today and the flexibility of science...

With the exception of providing advanced information to students sequentially throughout the lesson, Mark closely followed the overall PBL process taught in the CERTL workshop. Figure 11 presents Mark’s constructivist classroom observation scores. All three measures (learning direction, student engagement and constructivist principles) showed similar trends. Students assumed most of the direction of learning during the PBL lesson. Mark directed more of the lesson when giving notes and shared learning direction when students shared their information with the class. Constructivist principles, which followed the same pattern as learning direction, were well represented during the PBL lesson except during the notes component where constructivist principles were evident. Students exhibited moderate engagement when taking notes, moderately high engagement when sharing information with the class, and high engagement during the other components of the lesson.

While Mark felt strongly that students should take ownership and direct their own learning, he remained realistic stating,
Figure 11. Mark’s Classroom Observation Scores

It would be easy to say that the direction of student learning is decided by the students, but ultimately, I’m going to decide the direction. If I have everyone going off in their own direction, it’s almost impossible to manage people in 7 different places. It’s possible, but very difficult. I think that would be setting up for failure if you didn’t have at least some control over where they are.

He further elaborated commenting how

It would be nice to say they [students] could go in any directions they want. With the right group of kids you can give them a little more, you know, open it up a little more for them. But, there’s a certain end product that you are trying to get to. You want to get to six kingdom three domain systems. By letting them focus on protists the entire time we’re going to get off track, and we’re not going to end up at the same place….This is simply because of, you know, the standard course of study. It would be wonderful to say you go find something you’re passionate about and dive deep into it and I’m right behind you. I’ll be here to help if you need me. But when you’re trying to get them to focus on specific topics, it’s just not feasible.

For Mark, the standard course of study prevented him from allowing students to study topics that interest them most. When facilitating the PBL, Mark gave students some
choice in the direction of their learning. Students formulated the questions to research as part of solving the problem. The resource sheets Mark provided to students to help them solve the problem were based on the questions asked. Therefore, Mark thought he provided an environment where “the learning wasn’t necessarily parallel the whole way” and students “were given some choices.”

Constructivist learning environment principles were well represented during Mark’s facilitation of the PBL lesson components. During some problems, Mark facilitated a whole class discussion as a way of setting expectations. He did not have students share during every problem stating “I think it might get a little monotonous for them [students] to stop and share. Kind of breaks the continuity a little bit if we did it too often.” Mark maintained a good rapport and trust with his students, and for the most part, students responded by accepting their share of ownership of the learning environment. Students were randomly selected into cooperative groups by Mark drawing names written on popsicle sticks from a beaker, obviously a part of Mark’s normal routine. When asked how he helped to maintain positive collaboration, Mark responded,

by reading students’ body language from a distance… I can kind of pick up on what’s going on and jump in there and ask them what they’re doing to contribute. There wasn’t a lot of dissent amongst people as far as social interactions.

He was patient and flexible with students socializing a little in the learning environment. When necessary, Mark assigned a student in the group to keep the group on task or made comments on the group’s rubric sheet. While students were working in their small groups, Mark circulated around the room to each group as needed asking questions to formatively assess student understanding. He did not allow any one group to manipulate his time.
Mark credited student’s high level of engagement during most of the historical PBL instructional unit to the use of the students’ role in the PBL, the story line, and the activities. Throughout the first three days of the PBL, Mark made a point of reiterating to students that they were a taxonomist in 1956 and would be speaking at a conference. Mark thought this gave them a purpose and helped to motivate student learning. He concluded that the story line, which Mark aligned his notes to, created a nice flow for the lesson. Mostly, Mark thought the activity, a debate over how to classify green and brown algae, peaked student engagement. Mark remarked,

Students were told they needed to take a stance of where they want to put their brown algae and green algae. Where they want to classify it and why and just knowing that they were going to argue their opinion. I think they were more involved and more motivated to understand why not just where...they were passionate about it.

When facilitating the PBL components, Mark made a conscious effort to keep students engaged in learning by spending time with each small group, asking individual student’s different questions, providing microscopes and slides of organisms being studied, and having students share their thoughts with the class.

**Successes, Obstacles and Limitations when Facilitating Historical PBL lesson**

Mark identified ten successes, five obstacles and three limitations when teaching the historical PBL lesson. The results for Mark’s card sort activity are presented in Table 9. Mark categorized most of the successes as instructional design. He ranked personal relevance through students playing the role of a taxonomist, NOS understanding, historical story line, and higher order thinking as major successes. Specifically, Mark commented that the historical PBL helped students to view “that science should never be accepted as fact, that it’s flexible and changing, and it’s all about asking questions.” He
Table 9

Mark’s Categorization of Successes, Obstacles, and Limitations

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Category</th>
<th>Rating/Order</th>
</tr>
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<tbody>
<tr>
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<td>Personal relevance of role</td>
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<tr>
<td>Success</td>
<td>NOS understanding</td>
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<td>Success</td>
<td>Higher order thinking</td>
<td>ID</td>
<td>M-4</td>
</tr>
<tr>
<td>Success</td>
<td>Opportunity to review</td>
<td>MID</td>
<td>m-5</td>
</tr>
<tr>
<td>Success</td>
<td>Assessment product</td>
<td>ID</td>
<td>m-6</td>
</tr>
<tr>
<td>Success</td>
<td>Use of folders/responsibility</td>
<td>TE</td>
<td>m-7</td>
</tr>
<tr>
<td>Success</td>
<td>Identifying facts/questions</td>
<td>SL</td>
<td>m-8</td>
</tr>
<tr>
<td>Success</td>
<td>Assigning jobs</td>
<td>TE</td>
<td>m-9</td>
</tr>
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<td>Success</td>
<td>Active participation</td>
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<td>m-10</td>
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<td>End of course test</td>
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<td>M-1</td>
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<td>Lack of motivation</td>
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<td>Closing the PBL</td>
<td>ID</td>
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Abbreviations: ID=Instructional design; HID=Historical instructional design; SL=student learning; SA=school administration; MID=Modified instructional design; TE=teacher experience; M=major; m=minor

also thought the debate activity helped students to see the uncertainty of science. Minor successes Mark identified when teaching the historical PBL were categorized as instructional design, teacher experience and student learning.

Mark categorized obstacles and limitations as instructional design, school administration, and student learning. He viewed as a major obstacle his not being clear and concise about specifics of the PBL’s end product and as a minor obstacle his being unprepared when closing the PBL. Mark also felt a few students lacked the motivation at the beginning of the lesson commenting,

It was difficult to get some students to buy into it [the PBL lesson] and understand, because they want to know what do I have to do, what am I
making, what am I getting graded on. It took a little while for that to become clear. Because that is all they’re worried about is a grade. What do I need to do. Just tell me and I’ll do it so I’ll get an A or so I’ll get credit. For something that too so long to develop, it was a little bit of a barrier. Once it got flowing, they got pretty excited especially with the debate.

According to Mark, administration “is going to judge me by student test scores and by what students, and maybe other teachers, say about me.” Mark viewed end of course test scores as a major obstacle. Mark labeled as a minor limitation the county mandated pacing guide, which dictated when certain topics were to be taught. At the time of teaching the classification PBL, Mark was more than a week behind the pacing guide. For Mark, the pacing guide was not as constrictive as the end of course test. Another major limitation Mark identified was the social dynamics of two students who had an altercation outside of class. The school administration had not resolved the incident causing students to lose focus and Mark to spend time dealing with the issue. During the PBL, groups worked at different paces making it challenging for Mark to facilitate.

Cross-Case Analyses

The cross-case analysis is divided into three sections. The first section compares the participant’s alignment of instruction with constructivist principles using the six CLEQ subscales (Personal Relevance, Scientific Uncertainty, Critical Voice, Shared Control, Student Negotiation, and Attitude Scale). The second section compares the participant’s facilitation of the historical PBL. The third section compares the participant’s successes, obstacles and limitations when facilitating the historical PBL instructional unit.
Alignment of Instruction with Constructivist Principles

Participants’ mean perceived PBL and historical PBL personal relevance scores were both 27. These scores represent an overall high intermediate alignment with constructivist principles. Dana reported a high emphasis of both PBL and historical PBL for relating science to students’ everyday experiences. Beth viewed historical PBL to align with high intermediate agreement and PBL to align with high agreement and, therefore, found historical PBL as less (by four points) personally relevant to students than PBL. Both Emma and Mark scored with high intermediate agreement that PBL and historical PBL developed a meaningful context with respect to students’ real world.

Participants’ CLEQ comparison scores for personal relevance are exhibited in Figure 12.

![Figure 12. Personal Relevance CLEQ Comparison Scores](image)

Participants’ mean perceived PBL and historical PBL scientific uncertainty scores were 23 and 26, respectively. These scores represent an overall high intermediate alignment with constructivist principles. Dana reported a high emphasis of both PBL and historical PBL for presenting science as evolving and provisional. Both Beth and Mark
viewed with high intermediate agreement that PBL and historical PBL helped students to develop an idea of science changing over time. Emma, however, considered PBL to align with low intermediate agreement and historical PBL to align with high intermediate agreement, finding historical PBL more likely to develop students’ ideas that science is evolving and provisional. Participants’ CLEQ comparison scores for scientific uncertainty are exhibited in Figure 13.

![Figure 13. Scientific Uncertainty CLEQ Comparison Scores](image)

Participants’ mean recorded PBL and historical PBL critical voice scores were 27 and 29, respectively. These scores represent an overall increase from high intermediate to high alignment with constructivist principles. Beth, Dana, and Mark’s scores reflected little change with Dana showing a slight increase and Beth and Mark a slight decrease of both PBL and historical PBL presenting science as evolving and provisional. Both Beth and Mark viewed with high intermediate agreement that PBL and historical PBL allowed students to express concerns over obstacles to their learning. Emma reported a noticeable increase considering PBL to align with high intermediate agreement and historical PBL...
to align with high agreement. Participants’ CLEQ comparison scores for critical voice are exhibited in Figure 14.

![Figure 14. Critical Voice CLEQ Comparison Scores](image)

Participants’ mean perceived PBL and historical PBL shared control scores were 20 and 22, respectively. These scores represent an overall slight increase from high intermediate to high alignment with constructivist principles. Beth reported, to some extent, high emphasis of both PBL and historical PBL for designing and managing the learning environment. Dana viewed historical PBL with high agreement slightly more that historical PBL with high intermediate agreement as promoting student ownership over the learning environment. Both Emma and Mark viewed with low intermediate agreement that PBL and historical PBL finding historical PBL more likely to help students manage the learning environment. Participants’ CLEQ comparison scores for student choice are exhibited in Figure 15.
Participants’ mean reported PBL and historical PBL student negotiation scores were 26 and 28, respectively. These scores represent an overall high intermediate alignment with constructivist principles. Beth and Dana both reported high emphasis of both PBL and historical PBL for providing opportunities for students to explain and justify their thoughts by interacting verbally with other students. Both Emma and Mark viewed with low intermediate agreement that PBL and with high intermediate agreement that historical PBL helped students to negotiate and critically think about ideas. Participants’ CLEQ comparison scores for student negotiation are exhibited in Figure 16.

Participants’ mean perceived PBL and historical PBL student attitude scores were 23 and 26, respectively. These scores represent an overall high intermediate alignment with constructivist principles. Dana viewed with high agreement that the historical PBL and with high intermediate agreement that PBL motivated student learning. Beth considered with high intermediate agreement that PBL and historical PBL finding
historical PBL more likely to positively impact student interest and enjoyment. Mark reported the largest difference between PBL aligning to positive student attitude with low intermediate agreement and historical PBL aligning to positive student attitude with high intermediate agreement. Emma scored both PBL and historical PBL to align with low intermediate agreement. Participants’ CLEQ comparison scores for student attitude are exhibited in Figure 17.

Figure 16. Student Negotiation CLEQ Comparison Scores

Figure 17. Student Attitude CLEQ Comparison Scores
Facilitation of Historical PBL

Students of Dana and Mark had more experience learning via a PBL method than those of Beth and Emma. Dana, having previously implemented several PBL units and maintained a classroom practice that embraced PBL, executed the PBL lesson consistent with her normal teaching methods. Whereas Mark had not previously taught many PBL units, he had infused aspects of PBL into his teaching repertoire. Thus, students of both Dana and Mark were familiar with the PBL strategy. Beth, however, having not taught her students using PBL methods, combined her typical classroom instruction with the PBL components. Emma, not having a particular classroom routine, implemented the PBL lesson as advocated by CERTL. Having previously taught a PBL like activity once or twice, her students had little exposure to working in cooperative groups or with PBL.

All four participants began instruction by giving students notes followed by the first four components of CERTL’s PBL model. Additionally, Beth and Mark included an activity, which during the CERTL workshop was suggested as an optional component. For the majority of the lesson, Mark’s students directed most of their learning. Dana shared the direction of learning with her students during the first few components of the PBL lesson and then students assumed ownership over their learning for the final lesson components. Emma and Beth both directed most of the learning. However, Beth did implement an optional activity where students directed more of the learning. Figure 18 presents participants’ direction of learning as the historical PBL lesson progressed.
Student engagement during each component of the historical PBL lesson is presented in Figure 19. For Dana and Mark, student engagement remained high with between 61 to 80% of students actively participating throughout instruction. Both Dana and Mark were noted as having positive relationships with their students, which may have contributed to students’ active participation. Beth and Emma did not actively include their students during their notes component resulting in low student engagement. Beth’s student engagement increased to a high level (61 to 80% of students actively participating) during the remaining components of the lesson. Beth and Mark maintained high levels of student engagement during the optional activity component of the lesson. Emma’s students, however, displayed low levels (less than 40% of students actively participating) of student engagement during the PBL lesson. Interestingly, Emma was noted as having a negative rapport with her students and challenging classroom management issues.

The degree to which observed classroom instruction matched constructivist principles varied between participants. Mark’s observed PBL instruction showed the
highest representation of constructivist principles consistently throughout each component of the lesson. While not highly represented, evidence of constructivist principles were observed during Dana’s facilitation of the PBL lesson. Both Beth and Emma’s observed PBL instruction showed limited evidence of constructivist principles. Figure 20 presents a comparison of participants’ constructivist classroom observation scores during the historical PBL lesson.

Figure 19. Student Engagement Classroom Observation Comparison Scores

Figure 20. Constructivist Principles Classroom Observation Comparison Scores
Throughout the PBL lesson, Mark, Dana, and Emma reinforced the notion of students taking on the role of a taxonomist; thereby, supporting students’ personal relevance to the lesson. By incorporating a number of additional activities during class, Mark further enabled students to assume a taxonomist role and connect the learning experience to the real-world application of science. All four participants invited students to solve problems. However, Mark and Dana promoted student-ownership and inquiry the most by allowing students to direct more aspects of their learning. While students of all four participants worked in small groups, Mark incorporated more whole class discussion and reflection throughout the lesson. During the share component of the lesson, Dana provided an opportunity for student reflection.

**Successes, Obstacles And Limitations When Facilitating Historical PBL**

When facilitating the historical PBL instructional unit, participants recorded occurrences of successes, obstacles, and limitations. After teaching the lesson, each participant recorded their notes on index cards, categorized the event, decided if the event was major or minor, and then rank ordered the successes and then the obstacles/limitations. The resulting categories were totaled and entered in Table 10.

Participants categorized most of the successes as instructional design at 38.7% and student learning at 32.2%. Historical instructional design, modified instructional design, and teacher experience categories all contained an average of 9.7% of the classified successes. Participants considered students to think critically, relate well to the lesson’s story, perform well on the assessment product, and find the resources helpful and thus categorized instructional design as a success. Participants also categorized student
Table 10

Participant’s Categorization of Successes, Obstacles, and Limitations

<table>
<thead>
<tr>
<th>Category</th>
<th>Beth</th>
<th>Dana</th>
<th>Emma</th>
<th>Mark</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Successes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instructional design</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>38.7%</td>
</tr>
<tr>
<td>Historical instructional design</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>9.7%</td>
</tr>
<tr>
<td>Modified instructional design</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>9.7%</td>
</tr>
<tr>
<td>Teacher experience</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>9.7%</td>
</tr>
<tr>
<td>Student learning</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>32.2%</td>
</tr>
<tr>
<td><strong>Obstacles / Limitations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instructional design</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>18.8%</td>
</tr>
<tr>
<td>Modified instructional design</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>12.5%</td>
</tr>
<tr>
<td>Teacher experience</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>6.3%</td>
</tr>
<tr>
<td>Student learning</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>21.8%</td>
</tr>
<tr>
<td>School administration</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>40.6%</td>
</tr>
</tbody>
</table>

learning as successful in that students identified facts/questions to research, negotiated the problem, and maintained engagement. None of the successes were categorized as school administration. Participants categorized most of the obstacles/limitations as school administration at 40.6%. Student learning at 21.8%, instructional design at 18.8%, and modified instructional design at 12.5% accounted for the remaining obstacles/limitations. None of the obstacles or limitations was categorized as historical instructional design. In general, participants cited administrative issues as the main obstacle/limitation citing too high a focus on standards based learning and a lack of support in managing discipline problems.

During the card sort, participants delineated both their successes and their obstacles/limitations as major and minor. The sum of the participants’ data was then averaged to show a comparison between the groups resulting in Table 11. Beth and Mark identified the most successes with teaching the historical PBL instructional unit followed
Table 11

**Participant’s Major and Minor Successes, Obstacles, and Limitations**

<table>
<thead>
<tr>
<th>Category</th>
<th>Beth</th>
<th>Dana</th>
<th>Emma</th>
<th>Mark</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Successes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>61.3%</td>
</tr>
<tr>
<td>Minor</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>38.7%</td>
</tr>
<tr>
<td><strong>Obstacles / Limitations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>37.5%</td>
</tr>
<tr>
<td>Minor</td>
<td>8</td>
<td>1</td>
<td>9</td>
<td>2</td>
<td>62.5%</td>
</tr>
</tbody>
</table>

by Dana. Emma noted the fewest number of successes at five with three recognized as major and two as minor. Dana identified all six of her success as major. Overall, the participants identified more major success at 61.3% than minor at 38.7%. Emma identified the most obstacles/limitations categorizing them all as minor followed by Beth who identified eight minor obstacles/limitations. Both Dana and Mark noted six major obstacles/limitations and one and two, respectively, minor obstacles/limitations. Overall the participants identified more minor obstacles/limitations at 62.5% than major at 37.5%.

Each participant’s successes and obstacles/limitations were used to create a combined chart of the card sort activity in Table 12. The descriptors were arranged first by the number of participants to include that item and second by the ranking given to the item by participants. The top four successes were categorized as instructional design and student learning. All four participants placed higher order thinking as a major success. Active participation was also viewed, but to a lesser degree, as a success by all four participants. Three of the participants ranked the assessment product and identifying facts/questions as successful. At least two of the participants ranked successes as
Table 12

Participant’s Categorization and Ranking of Successes, Obstacles, and Limitations

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Category</th>
<th>Beth</th>
<th>Dana</th>
<th>Emma</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success</td>
<td>Higher order thinking</td>
<td>ID</td>
<td>M-6</td>
<td>M-2</td>
<td>M-2</td>
<td>M-4</td>
</tr>
<tr>
<td>Success</td>
<td>Active participation</td>
<td>SL</td>
<td>M-1</td>
<td>M-4</td>
<td>m-4</td>
<td>m-10</td>
</tr>
<tr>
<td>Success</td>
<td>Assessment product</td>
<td>ID</td>
<td>M-5</td>
<td>M-3</td>
<td>m-6</td>
<td>m-6</td>
</tr>
<tr>
<td>Success</td>
<td>Identifying facts/questions</td>
<td>SL</td>
<td>M-2</td>
<td>M-5</td>
<td>m-8</td>
<td>m-8</td>
</tr>
<tr>
<td>Success</td>
<td>Negotiating problem</td>
<td>SL</td>
<td>M-3</td>
<td>M-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>NOS understanding</td>
<td>HID</td>
<td>M-4</td>
<td></td>
<td>M-2</td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>Personal relevance of role</td>
<td>ID</td>
<td></td>
<td>m-5</td>
<td>M-1</td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>Use of pictures</td>
<td>MID</td>
<td>m-10</td>
<td>M-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>Assigning jobs</td>
<td>TE</td>
<td>m-7</td>
<td></td>
<td></td>
<td>m-9</td>
</tr>
<tr>
<td>Success</td>
<td>Thoughtful discussions</td>
<td>ID</td>
<td></td>
<td>M-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>Student enjoyment</td>
<td>SL</td>
<td></td>
<td></td>
<td>M-3</td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>Historical story line</td>
<td>HID</td>
<td></td>
<td></td>
<td>M-3</td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>Opportunity to review</td>
<td>MID</td>
<td></td>
<td></td>
<td>m-5</td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>Use of folders/ responsibility</td>
<td>TE</td>
<td></td>
<td></td>
<td>m-7</td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>Instructional time</td>
<td>ID</td>
<td>m-8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Success</td>
<td>Helpful resources</td>
<td>ID</td>
<td>m-9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Lack of motivation</td>
<td>SL</td>
<td>M-3</td>
<td>m-3</td>
<td>M-2</td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Instructional time</td>
<td>ID</td>
<td></td>
<td>M-4</td>
<td>M-5</td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>End of course test</td>
<td>SA</td>
<td>m-4</td>
<td></td>
<td>M-1</td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Lack of specifics</td>
<td>MID</td>
<td>m-8</td>
<td></td>
<td>M-3</td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Continuous focus</td>
<td>SL</td>
<td></td>
<td>M-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Lack of preparation</td>
<td>TE</td>
<td></td>
<td>m-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Including book work</td>
<td>MID</td>
<td>m-5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Lack of collaborative culture</td>
<td>TE</td>
<td></td>
<td>m-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Questioning technique</td>
<td>SL</td>
<td></td>
<td>m-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Naive student reflections</td>
<td>ID</td>
<td>m-6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Introducing the PBL</td>
<td>MID</td>
<td>m-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstacle</td>
<td>Closing the PBL</td>
<td>ID</td>
<td></td>
<td></td>
<td></td>
<td>m-8</td>
</tr>
<tr>
<td>Limitation</td>
<td>Pacing guide / SCOS</td>
<td>SA</td>
<td>m-2</td>
<td>m-7</td>
<td>m-7</td>
<td>m-7</td>
</tr>
<tr>
<td>Limitation</td>
<td>Social dynamics</td>
<td>SA</td>
<td>M-5</td>
<td>m-1</td>
<td>M-6</td>
<td></td>
</tr>
<tr>
<td>Limitation</td>
<td>Administrative support</td>
<td>SA</td>
<td>M-1</td>
<td>m-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limitation</td>
<td>Groups in different places</td>
<td>ID</td>
<td></td>
<td></td>
<td>M-4</td>
<td></td>
</tr>
<tr>
<td>Limitation</td>
<td>Tracking</td>
<td>SA</td>
<td></td>
<td>M-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limitation</td>
<td>Required weekly quizzes</td>
<td>SA</td>
<td>m-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limitation</td>
<td>Uncooperative groups</td>
<td>SL</td>
<td>m-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limitation</td>
<td>Different type of learning</td>
<td>ID</td>
<td></td>
<td>m-8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limitation</td>
<td>Lack of ability</td>
<td>SL</td>
<td></td>
<td>m-9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: ID=Instructional design; HID=Historical instructional design; SL=student learning; SA=school administration; MID=Modified instructional design; TE=teacher experience; M=major; m=minor
negotiating the problem, understanding nature of science, the role of personal relevance, use of pictures, and assigning students with jobs. None of the successes were attributed to school administration. The top four obstacles encompassed four different categories (student learning, instructional design, school administration, and modified instructional design). Three of the participants placed lack of student motivation as an obstacle. Two of the participants ranked limited instructional time, end of course test, and lack of specifics as additional obstacles. The top four limitations were categorized as school administration. All our participants ranked the county mandated pacing guide and the state standard course of study as minor limitations. Three of the participants placed social dynamics as a limitation, and two of the participants ranked administrative support as a limitation.

**Summary**

The CLES questionnaire, observations, interviews, and card sort activity provided evidence of participants’ alignment of PBL instructional practices to constructivist principles and their facilitation of historical PBL instruction. According to Savery & Duffy (1995) successful implementation of PBL instruction relies on teacher’s alignment to constructivist learning principles. Survey responses portrayed two participants, Dana and Beth, as aligning PBL to constructivist practices with high to high-intermediate agreement and two participants, Mark and Emma, as aligning PBL to constructivist principles with high-intermediate to low-intermediate agreement. Observations showed implementation of constructivist practices to be represented in Mark and Dana’s instruction and less evident in Beth and Emma’s teaching. A discrepancy appeared to
exist with Mark and Beth’s perceptions of classroom practice aligning to constructivist principles, which could be attributed to the participants interpretation of the CLEQS questions or to researcher bias during observations.

Mark had built positive relationships with his students. He adapted his classroom routine to incorporate components of PBL. Beth had a neutral rapport with her students. She modified PBL components to match her classroom routine. Like Mark, Dana had a positive rapport with her students. Having fully embraced the PBL teaching strategy, she had designed classroom procedures consistent with the teaching of PBL. Emma had negative relationships with her students. She attempted to teach PBL without having established a consistent classroom structure.

All four participants used the historical storyline to teach the PBL in an historical context. They felt that the PBL instructional unit helped students to understand how science is flexible and changes over time and that science needs evidence. NOS understandings were listed as a success by two of the four participants. Other success attributed by participants to instructional design included higher order thinking, assessment product, and personal relevance of role. Participants also thought student learning contributed to successful active participation, identifying facts and questions, and negotiating the problem. Major obstacles listed by participants included student motivation and lack of instructional time due to end of course testing. The top limitations to facilitating the PBL were all attributed to school administration and included keeping to the county mandated pacing guide, social dynamics and administrative support.
CHAPTER 5
CONCLUSIONS

This study is an exploratory investigation into the facilitation of PBL and the potential for implementing a historical PBL instructional unit. Two questions guided this study. Question one explored participants’ perception of instructional alignment with constructivist principles. The second question examined participants facilitation of a historical PBL instructional unit. Four teachers with varying degrees of experience and similar PBL training through the CERTL workshop took part in this study. Their participation included completing classroom learning environment questionnaires; sharing thoughts and ideas during two interviews; agreeing to be observed while teaching a historical PBL instructional unit on classification of living organisms; and completing a card sort activity to organize successes, obstacles, and limitations encountered when facilitating the lessons. As the groundwork in an expedition to identify the pedagogical issues inherent in implementing historical PBL investigational units, a reference point for future investigations was generated in this study.

Importance of this Study

National Standards (NRC, 1996) recommend the type of reform-based student-centered instruction that a constructivist teaching strategy, like PBL, exemplifies. Also included as standard G in the NSES and AAAS publications (1989; 1993) are a focus on
teaching history and NOS. The goal is to assist students with learning science as a human endeavor, nature of scientific knowledge, and historical perspectives of science. Some scholars, such as Martin (1972), Matthews (1992), and Allchin (2000), advocate for a focused approach to teaching secondary students history and philosophy of science. Allchin (2000) specifically recommended using historical cases, but falls short of suggesting a teaching strategy. A PBL instructional unit that incorporates a historical case study, similar to the lessons teachers used in this study, satisfies reform-based curriculum emphasis and places learning in a historical context. Exploring the alignment of teachers’ perception of PBL instruction to constructivist principles and evaluating the potential for teaching PBL in a historical context were a focus of this study.

Prior to this study, limited research had been reported about PBL in secondary classrooms, particularly research in the achievements and barriers experienced by teachers when facilitating PBL. Some studies do highlight the potential gains in cognitive thinking, independent learning, collaborative working skills, and interest in content (Smith, 1995; Sonmez & Lee, 2003). Challenges faced by teachers to adopt PBL have been identified as inadequate material resources, limited implementation time, large class sizes, and support from administrators (Barron et. al., 1998). One area of needed research cited by Thomas (2000) and Hmelo-Silver (2004) involved how teachers facilitate PBL. Investigating four teachers’ implementation of a historical PBL instructional unit was another focus of this study.
Discussion of Results

Research Question 1: How do teachers’ PBL instructional practices align with constructivist principles? Overall, participants’ self-reported PBL instruction aligned with high intermediate agreement to constructivist principles. Mark and Emma scored alignment to constructivist principles as the lowest followed by Beth and then Dana. Prior to teaching the historical PBL lesson, both Mark and Emma scored PBL as aligning to constructivist principles with low intermediate agreement. Their responses on the CLEQ increased to high intermediate agreement after teaching the historical PBL lesson. Both Mark and Emma viewed historical PBL as providing a classroom environment more inviting for students to express concerns about their learning and better at assisting students with interacting verbally with other students. Additionally, Emma felt historical PBL improved student engagement in scientific uncertainty while Mark expressed a belief that student attitude was more positive with the historical PBL lesson. Beth and Dana remained consistent aligning both PBL and historical PBL with high intermediate and high agreement, respectively.

PBL is an instructional design strategy grounded in constructivism where students become willing and active participants in the learning process. As such, classroom culture plays an important role in teacher’s alignment to constructivist principles and effectiveness of practice. Classroom culture refers to the unspoken and often unconscious assumptions about how both the teacher and students conduct themselves during the learning environment. Brown (2005) attributed a classroom culture based on respectful relationships between students and teachers to effective communication.
According to data from the CLEQ instrument, the two experienced participants, Dana and Beth, aligned to a higher degree than the two novice participants, Mark and Emma, with reform-based constructivist principles. In practice; however, observations and interviews showed constructivist principles to be more represented in Mark and Dana’s instruction than Beth and Emma’s teaching. Teachers of this study who aligned higher with constructivist practices, Dana and Mark, had developed positive relationships with students and maintained an encouraging classroom culture. When comparing the total obstacles to successes for each teacher, Dana and Mark experienced twice as many successes. This study is inline with the thoughts of Sonmez & Lee (1997) who ascribe the effectiveness of PBL, in part, to “the nature of student engagement and the culture of the classroom” (p. 2).

Research Question 2: How do teachers facilitate historical PBL instruction? The results of this study were consistent with Stigler & Hiebert (1999) contention that teachers modify features to fit within their current system, but less with their assertion that the apparent change in surface features does not fundamentally change the nature of instruction. Due to the constructivist principles inherent in PBL (Savery & Duffy, 1995), the teachers of this study facilitated instruction more consistent with reform-based student-centered curriculum. Integrating a new instructional method to fit within a teacher’s current system is in agreement with existing literature. As shown in the data, three of the four teachers, Beth, Dana, and Mark, used preexisting classroom structures to facilitate the historical PBL instruction. Emma, not appearing to have a classroom routine in place, was the one teacher who taught the historical PBL instructional unit without modifying an existing classroom structure.
Mark and Dana, having previously modified their classroom teaching to include the components of PBL learned during the CERTL workshop, were well prepared to facilitate the historical PBL instructional unit. Mark kept his routine of lecturing to students, but geared the notes presented to students on the daily PBL topic. He also incorporated additional activities typical of his instruction, such as viewing organisms being researched under microscopes. Dana developed a CHAMP management system with colored zones to structure student learning by providing students with behavioral expectations. The green zone (group work/lab) was developed to assist with facilitating PBL. Throughout the instructional unit, both Mark and Dana consistently interacted with all students circulating amid student groups, listening in on their conversations, asking questions, and responding to queries. Neither allowed one group to dominate their time. If Dana found she was at a table of students for more than a few minutes, she would tell students to keep thinking and that she would be back. Mark and Dana had structures in place that helped them become comfortable with giving control of the learning over to students.

Beth and Emma were less prepared to facilitate the historical PBL instructional unit. Neither teacher had the classroom structure in place for managing a constructivist classroom. While Beth made surface changes to fit PBL features into her lessons, she made less fundamental changes to the nature of instruction than the other participants. Beth maintained her notes, textbook readings and worksheets, and homework assignments from previous years of teaching the topic. Thus, her instruction did not flow with the PBL lessons. For example, when the PBL presented to students only a four kingdom classification system, students were learning through textbook readings and
note taking about a six kingdom scheme. In stark contrast to Beth, Emma did not have much of a classroom structure in place admitting to not using her CHAMP management system effectively. During the instructional unit, Emma divided her time between administrative type tasks and assisting students, which substantially reduced the amount of time spent working with students. When Beth or Emma were interacting with students, one or two groups would frequently dominate their time. Both Beth and Emma focused on helping one group of students sometimes for more than five minutes.

Participants who had an established teaching routine taught the historical PBL instructional unit to fit within their teaching systems. The two teachers, Dana and Mark, with classroom practices that supported cooperative learning attributed less obstacles and limitations to student learning. Beth, whose classroom practice included giving students jobs to perform during group work, noted uncooperative groups as a limitation to facilitating the PBL lessons. Emma established having a lack of cooperative learning culture and being unprepared as minor obstacles to her facilitating the PBL instructional unit. Despite differences in facilitating the lessons, the PBL approach helped the teachers align their practice more toward reform-based constructivist principles.

*Research Question 2a: Why might teachers experience pedagogical successes, obstacles, and limitations while facilitating historical PBL lessons?*

Problem-based learning is an instructional strategy for curriculum design, and as such leads students through a process which involves objectives, problems, research experiences, solution development activities, and assessments (Torp & Sage, 1998). As with any instructional strategy, teachers will optimistically experience successes and most certainly will encounter obstacles and limitations. Some of the successes the
participants of this study identified include each aspect of the instructional design process. Successful objectives included student higher order thinking and NOS understanding. The problems were cited as helping students to identify facts and questions. Research experiences provided opportunities for students to successfully negotiate the problem, actively participate, and relate to the story. Solution development activities were listed as offering helpful resources and assisting with thoughtful discussions. The assessment products were also listed as a success in that they helped students to demonstrate enduring understanding of the lesson objectives. While participants attributed their many successes to the instructional design, the CERTL workshop provided the understanding for implementing the design process.

Participants encountered several obstacles when facilitating the historical PBL instructional unit. The obstacles attributed to students were lack of motivation and focus. By confronting these obstacles, Mark and Dana did not experience the level or degree of off task behavior, as did Beth and Emma. One key difference was how Mark and Dana constantly observed student behavior and monitored their progress toward solving the problems. Additionally, Mark and Dana guided their students to experience the PBL learning strategy throughout the year and were comfortable with sharing control of the learning environment with students. Emma and Beth, however, desired to be more in control of the learning environment, which created a dilemma in terms of sharing control with students. Also, Emma cited her lack of experience, failure to create a collaborative culture, and feeling unprepared as sources for these obstacles. Observations indicated that Emma’s strained relationship with her students negatively impacted her ability to facilitate lessons. Continual monitoring of student progress, providing students with
collaborative experiences, and having a positive rapport with students appear to lessen the challenges with facilitating the historical PBL lesson.

Most limitations mentioned by participants were issues under the purview of school administrators. Participants felt constrained with time limitations as the county mandated pacing guide afforded three days to teach the objectives associated with the historical PBL lesson. Also, teachers felt constrained to teach to the end of course test. Current research studies point to accountability and high stakes tests as vital factors for teacher dissatisfaction (Donnelly & Sadler, 2009). Social dynamics was another major limitation as teachers and students were distracted with student-student issues when out-of-class fights and suspensions caused tension within the class. All participants had the support of their administration at the time of completing the CERTL workshop. However, Dana and Emma had different administrators in place when participating in this study. They eluded that administrators unsupportive of the different learning process hindered implementation of PBL.

Research Question 2b: What is the possibility of teaching history and nature of science through PBL instruction? The teachers of this study found having students follow the historical story line through PBL introduced students to some NOS understandings. All four participants agreed that the historical PBL helped students to view science as evolving and provisional. Beth commented that the lesson addressed how science changes over time and how science needs evidence. Likewise, Dana thought the historical PBL provided students with a view that science is progressive and changes over time. Emma mentioned that historical PBL portrays science as not static; she pointed out how it has changed in the past and may change in the future. Finally, Mark thought the historical
PBL demonstrated to students how science should never be accepted as fact, is flexible and changing, and is all about asking questions.

Unfortunately, participants only addressed a few NOS concepts explicitly through questions, guided reflection, and instruction that emphasized relevant aspects of NOS (Schwartz & Lederman, 2002) to students. While not all NOS tenets (McComas et. al., 1998) were addressed in the historical PBL instructional unit taught during this study, the following were possible: scientific knowledge is durable yet tentative, scientific knowledge can proceed through observation, science proceeds through curiosity and attempts to explain natural phenomena, new scientific knowledge is clearly and openly reported, history reveals that science is dynamic and on-going and has evolutionary and revolutionary characteristics, scientists are imaginative, and historical events influence scientific ideas. Evaluating participants’ views of NOS was beyond the scope of this study. However, based on limited interview questions regarding NOS, participants appeared to have a naïve understanding of NOS.

Dana summarized the participants’ thoughts on how PBL differed from historical PBL best stating, “PBLs are just PBLs to me. The historical just has to do with the topic more than it has to do with anything else.” Comparing PBL to historical PBL CLEQ scores confirmed Dana’s opinion for all four participants. When asked if they planned on teaching the lesson again to future students, all four participants said yes. In general, participants liked how the historical PBL instructional unit flowed, provided a context for learning, and told a story.
Implications and Recommendations

A finding of this study highlighted the importance of creating a collaborative classroom culture and building positive student-teacher relationships. Providing students with opportunities to develop collaborative learning skills in a caring and supportive environment assists with successful implementation of PBL. Teachers can conduct small one class-period events throughout the semester to help students learn the expectations for working in small groups. When facilitating small group activities, a teacher’s close proximity to students and circulation throughout the classroom is important. Teachers should avoid allowing any group of students to dominate their attention. One way to accomplish not getting cornered by one group for extended periods of time is to take Dana’s approach. She would honor students’ questions by listening, providing a short response and then leaving the group to continue thinking. Dana’s method is a good example of Noddings (2006) assertion that “caring teachers listen and are responsive” (p. 341; Noddings, 2003). Mark demonstrated another means of caring when he dedicated a diminutive portion of class time to open discussion of various students’ interests and daily lives.

This study concurred with similar studies reported by Stigler & Hiebert (1999) of teachers assimilating system changes to fit within preexisting routines instead of changing current system. These studies define systems of teaching as factors that influence how teachers teach. Such features could include the physical setting of the classroom, resources such as textbooks, standards, pacing guides, the role of students, and daily school schedules (i.e. 50-minute or 90-minute class times) (Stigler & Hiebert, 1999). When offering professional development opportunities for learning a novel
teaching strategy such as PBL, teachers’ current systems need to be valued and incorporated into instruction. By assisting teachers with assimilating PBL into preexisting routines, professional development instructors can best maintain the integrity of the strategy so that constructivist principles and NOS understandings are encouraged.

The participants in this study concurred with low intermediate to high intermediate agreement that PBL aligned with constructivist principles. However, in theory PBL actually aligns with high agreement to constructivist principles (van Berkel & Schmidt, 2000; Savery & Duff, 1995). The difference between theory and practice could be attributed to accountability measures imposed by school administration. Research studies involving accountability measures, such as end of course testing, cite teaching to the test (Shaver, Cuevas, Lee, and Avalos, 2007), eliminating nontested material (Abrams, Pedulla, & Madaus, 2003), and minimizing student-centered instruction (Bianchini & Kelly, 2003) as concerns (Donnelly & Sadler, 2009). To better reconcile this difference between theory and practice, teachers should understand how components of the PBL strategy encourage reform-based constructivist practices. This study revealed that the role students assume as part of the PBL problem helps to develop a real-world application and personal relevance. Allowing students to manage research activities affords them an opportunity to share control. Having students share their findings is an occasion for student negotiation to occur when explaining, justifying, and critically reflecting on the viability of ideas.

Providing teachers with information on NOS should be another area of focus for teaching historical PBL. The teachers in this study considered PBL to align with high intermediate agreement with scientific uncertainty. One of the few NOS views taught to
students during the instructional unit was the concept that science was evolving and provisional. This study revealed that opportunities to further students’ NOS understandings exist through historical PBL instruction; however, teachers should be conscious of the various NOS tenets that can be explicitly emphasized during instruction (Khishfe & Abd-El-Khalick, 2002). One suggestion for increasing teachers’ NOS understandings is to include more NOS instruction in teacher certification and professional development courses.

CERTL requires all teachers to provide written support from their school administration as a prerequisite for taking the PBL workshop. Having a principal supportive of an inquiry approach to teaching that involves student chatter, movement, and controlled chaos was cited as important for successful implementation of PBL. Inviting principals of teachers using PBL to participate in a portion of the workshop when classroom management is being discussed might assist administrators to better understand the classroom environment when teaching science by inquiry. A uniform limitation expressed by study participants was the perceived constraints placed upon teachers by curriculum administrators. By working with developers of the county mandated pacing guide, perhaps required curriculum topics could be reduced so that more time could be spent on fewer important concepts, which would give teachers the time necessary to implement instructional strategies like PBL. Not until administrators at all levels fully understand reform-based science curriculum can they be supportive of teachers implementing such practices as PBL.

This study revealed two important findings thus providing major contributions to science education research. First and foremost, promoting a collaborative learning
environment and building positive student-teacher relationships are important aspects to the success of teaching with reform-based constructivist principles. Accomplished facilitation of PBL involved circulating throughout the classroom constantly during instruction, limiting the time spent with student groups, engaging students to critically think, honoring students question, reading students body language, and not engaging students in power struggles. Second, the teachers participating in this study assimilated the PBL instructional strategy into their preexisting classroom structures. Thus, integrating reform-based teaching strategies involved valuing teachers current systems and pushing teachers to align their practice more with constructivist principles. Additionally, a supportive administration is a necessary component in closing the gap between theory and practice.

Suggestions for Further Research

Future research should address the benefits of historical PBL instruction from the perspective of the students. This study depicted how teachers aligned historical PBL instruction to constructivist principles, which may be different from how students viewed the classroom learning environment. Exploring students’ perceptions by giving students the CLES instrument would provide educators with insight into students’ views. How do the experiences students encounter during a historical PBL instructional unit align with reform-based constructivist principles? Another area of research would be to assess the impact of historical PBL instruction on students’ understandings of NOS. Background literature highlights the potential for NOS tenets to be addressed through historical PBL lessons especially in classrooms of teachers with sophisticated NOS understandings.
Investigating the effects of historical PBL instruction on students’ NOS understandings would help in determining the value of historical PBL as an instructional strategy for meeting NOS objectives.

An additional area of future research should involve studying the impact of a PBL workshop on teachers’ classroom management. In what ways do teachers change their classroom practices when teaching PBL or modify PBL to fit their classroom systems, and what effects, if any, do teachers’ adaptations have on the integrity of PBL? As a constructivist-based strategy, PBL requires classroom systems that promote students taking ownership of learning. Further investigation of ways in which teachers foster collaborative classroom cultures and positive student-teacher relationships is warranted. The PBL workshop offered by CERTL focuses not only on a method of instruction, but more importantly on teachers designing their own PBL lessons. Therefore, teachers might fundamentally change the nature of their instruction in a way that best supports science reform-based curriculum.

Summary

Both the NRC (NRC, 1996) and AAAS (1989; AAAS, 1993) specify the necessity to teach history and NOS as a component for achieving scientific literacy, and recommend a more constructivist approach to teaching. What these organizations seem to be encouraging is similar to the Japanese teaching strategies observed in the TIMSS investigation (Stigler & Hiebert, 1999), which place an emphasis on content in a student-centered approach. Allchin (2000) suggested placing a historical case as the central context for teaching as a method of achieving science literacy in history and nature of
science. By teaching science using PBL in a historical context, the participants in this study were able to provide a storyline for students to follow as they learned the content.

Professional development workshops, like the one offered to teachers by CERTL, prescribes a shift from discipline-based instruction to a reform-based or constructivist paradigm. PBL embodies constructivist-learning principles and offers challenges for teachers when facilitating and adapting PBL instruction in the curriculum. The purpose of this study was to investigate teachers’ perceptions and facilitation of their classroom-learning environment during historical PBL science instruction. By examining teachers’ instructional learning environment and perceived barriers and accomplishments teachers encountered while facilitating a historical PBL instructional unit, a foundation for identify the pedagogical issues inherent and a reference point for future investigations was generated.

The experienced teachers participating in this study perceived PBL to align with reform-based constructivist principles to a higher degree than the two novice teachers. In practice, classroom culture played an important role in teacher’s alignment to constructivist principles. The teachers who developed a collaborative learning culture and positive student-teacher relationships experienced more successes than barriers when facilitating historical PBL instruction. Additionally, the two more effective teachers significantly modified their preexisting teaching systems in a way that fundamentally changed their nature of instruction while the two less effective teachers modified their preexisting teaching systems but not their nature of instruction.

All four teachers participating in this study found historical PBL instruction to provide a positive learning experience. They agreed that the instructional unit flowed,
provided a historical context for learning, and told a story that could effectively engage most students. Participating teachers mentioned only a few NOS tenets expressed during the historical PBL instructional unit, which was attributed to the teachers’ naïve NOS understandings. Educating teachers about how historical PBL addressed more NOS tenets might increase the attention paid to NOS objectives.

The findings from this study revealed the importance of creating a collaborative classroom culture and building positive student-teacher relationships when implementing PBL instruction. One means of creating a collaborative learning environment is to set expectations by providing frequent opportunities for students to work in groups, especially during the beginning of the school year. Caring teachers who listen and are responsive to their students establish positive relationships and experience fewer challenges with students when facilitating PBL instruction. Since PBL is a time intensive instructional strategy, and one involving an active inquiry approach not familiar to many administrators, supportive and understanding administrators are necessary for teachers to create a learning environment which supports PBL instruction.

Historical PBL offers a strategy for teaching the NSES content standards and thus promoting the attainment of scientific literacy. This study provides evidence that teaching science in a historical context using a PBL approach can be effective. Despite the barriers encountered during instruction, teachers participating in this study viewed their lessons as successful and provided valuable insight into ways to facilitate PBL instruction.
References


Journal of College Science Teaching, 23(4), 221-229.


APPENDIXES

APPENDIX A1

SCIENCE CLASSROOM LEARNING ENVIRONMENT QUESTIONNAIRE\textsuperscript{1,2}

TEACHER PERCEPTIONS

Directions

1. This questionnaire asks you to describe your classroom, as a whole. There are no right or wrong answers. Your opinion and perception of your class during PBL instruction, in general, is what is wanted.

2. On the next few pages you will find 42 sentences. For each sentence, circle one number corresponding to your answer.

For example:

<table>
<thead>
<tr>
<th>During this historical PBL . . . Students ask each other questions.</th>
<th>Almost Always</th>
<th>Often</th>
<th>Sometimes</th>
<th>Seldom</th>
<th>Almost Never</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

- If you think students almost always asks other students questions, circle the 5.
- If you think students almost never asks other students questions, circle the 1.
- Or you can choose the number 2, 3 or 4 if this seems like a more accurate answer.

3. Teacher Name: ___________________________

4. School Name: ____________________________

\textsuperscript{1}adapted from Constructivist Learning Environment Survey, P. Taylor, B. Frasher, & L. White, Curtin University of Technology.

\textsuperscript{2}used with permission from Dr. Peter Taylor
5. Now complete the questionnaire and please give an answer for every question.

<table>
<thead>
<tr>
<th>During this historical PBL . . .</th>
<th>Almost Always</th>
<th>Often</th>
<th>Sometimes</th>
<th>Seldom</th>
<th>Almost Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Students learn about the world outside of school.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2 Students learn that scientific theories are human inventions It’s OK for students to ask the teacher “why do we have to learn this?”</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3 Students help the teacher to plan what they are going to learn. Students get the chance to talk to other students about their ideas. Students display actions that suggest they look forward to the learning activities.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>7 New learning starts with problems about the world outside of school.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>8 Students learn that science is influenced by people’s values and opinions.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>9 Students are free to question the way they are being taught.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10 Students help the teacher decide how well their learning is going.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>11 Students talk with other students about how to solve problems.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>12 Students appeared engaged and interested in the activities.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
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<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>13</td>
<td>Students learn how science can be part of their out-of-school life.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>Students learn that views of science have changed over time. It’s OK for students to voice concerns about activities that are confusing. Students have a say in deciding the rules for classroom discussion.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>Students try to make sense of other students’ ideas. The activities increase students’ interest in science.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>Students get a better understanding of the world outside of school. Students learn about the different science used by people in other cultures. It’s OK for students to voice concerns about anything that stops them from learning. Students have a say in deciding how much time they spend on an activity. Students ask other students to explain their ideas. Students appear to enjoy the learning activities.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>
During this historical PBL . . .

<table>
<thead>
<tr>
<th></th>
<th>Almost Always</th>
<th>Often</th>
<th>Sometimes</th>
<th>Seldom</th>
<th>Almost Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Students learn interesting things about the world outside of school.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>26</td>
<td>Students learn that scientific knowledge can be questioned.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>27</td>
<td>Students are free to express their opinion.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>28</td>
<td>Students ask each other to explain their ideas.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>29</td>
<td>Students appear to be confused. What students learn has nothing to do with their out-of-school life.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

During this historical PBL . . .

<table>
<thead>
<tr>
<th></th>
<th>Almost Always</th>
<th>Often</th>
<th>Sometimes</th>
<th>Seldom</th>
<th>Almost Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>Students learn that science reveals the secrets of nature.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>32</td>
<td>It’s OK for students to speak up for their rights.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>33</td>
<td>Students are given a say in deciding what will be on the test.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>34</td>
<td>Students explain their ideas to each other.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>35</td>
<td>Students appear to view the learning activities as a waste of time.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>36</td>
<td>Students have a say in deciding what activities they do.</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>
## SCORING GUIDELINES FOR THE CLEQ

This instrument consists of both positive and negative statements which teachers must answer on a scale that ranges from “Almost Always” to “Almost Never.” For positive item statements, the “Almost Always” choice would receive a 5 moving on down to the “Almost Never” choice which would receive a 1. For negative item statements, the numbering procedure is reversed.

For example:

<table>
<thead>
<tr>
<th>Item</th>
<th>Statement</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>Students learn about the world outside of school.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(+) Students learn has nothing to do with the world outside of school.</td>
<td>5 4 3 2 1</td>
</tr>
<tr>
<td>38</td>
<td>Students learn that scientific knowledge is beyond doubt.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-) Students appear to feel unable to complain about anything.</td>
<td>5 4 3 2 1</td>
</tr>
<tr>
<td>39</td>
<td>Students appear to feel unable to complain about anything.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-) Students have a say in deciding how their learning is assessed.</td>
<td>5 4 3 2 1</td>
</tr>
<tr>
<td>40</td>
<td>Students pay attention to each other’s ideas.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-) Students appear to feel tense.</td>
<td>5 4 3 2 1</td>
</tr>
</tbody>
</table>

Sample item one would be scored as a 4 while sample two would be scored as a 2. The total score would be $4 + 2 = 6$, in this example.
I. PERSONAL RELEVANCE SCALE (PR)

This scale is concerned with students’ experience of the personal relevance of school science. The scale has been designed to measure the extent to which students perceived the relevance of school science to their out-of-school lives. From a constructivist perspective, the classroom environment should not promote a discontinuity between school science and students’ out-of-school lives by evoking an abstract and decontextualized image of science. Rather, the classroom environment should engage students in opportunities:
1. to experience the relevance of school science to their everyday interests and activities;
2. to use their everyday experiences as a meaningful context for the development of their formal scientific knowledge.

Items:
1. (+) 30. (-)
7. (+) 37. (-)
13. (+)
19. (+)
25. (+)

II. SCIENTIFIC UNCERTAINTY SCALE (SU)

This scale is concerned with students’ perceptions of science as a fallible human activity. The scale has been designed to measure the extent to which students perceive science to be an uncertain and evolving activity embedded in a cultural context and embodying human values and interests. From a constructivist perspective, the classroom environment should not promote: (1) a scientistic view of science as a supreme universal monocultural activity that is independent of human interests and values; or (2) the objectivist myth that science provides an accurate and certain representation of objective reality (i.e., a correspondence theory of truth). Rather, the classroom environment should be concerned with engaging students in opportunities to learn to be skeptical and critical about the nature and value of science. In particular, to learn:
1. that scientific knowledge is evolving and provisional;
2. that scientific knowledge is shaped by social and cultural influences;
3. that scientific knowledge arises from human interest and values.

Items:
2. (+) 31. (-)
8. (+) 38. (-)
14. (+)
20. (+)
26. (+)
III. CRITICAL VOICE SCALE (CV)

This scale is concerned with students’ development as autonomous learners. In particular, the scale has been designed to measure students’ perceptions of the extent to which they are able to exercise legitimately a critical voice about the quality of their learning activities. From a constructivist perspective, the classroom environment should not favor technical curriculum interest (e.g., covering the curriculum content) to an extent that accountability for classroom activities is directed largely towards an external authority. Rather, the teacher should be willing to demonstrate his/her accountability to the class by fostering students’ critical attitudes towards the teaching and learning activities. This can be achieved by creating a social climate in which students believe that it is legitimate and beneficial
(1) to question the teachers’ pedagogical plans and methods;
(2) to express concerns about any impediments to their learning.

Items:
3. (+) 39. (-)
4. (+)
15. (+)
21 (+)
27. (+)
32. (+)

IV. SHARED CONTROL SCALE (SC)

This scale is concerned with another important aspect of the development of student autonomy, namely students sharing with their teachers control of the classroom learning environment. In particular, the scale has been designed to measure students’ perceptions of the extent to which the teacher involves them in the management of the classroom learning environment. From a constructivist perspective, students should not be required to adopt the traditional role of compliant recipients of a predetermined pedagogy that is controlled entirely by the teacher. Rather, the teacher should invite students to share control of important aspects of their learning by providing opportunities for them to participate in the process of:
(1) designing and managing their own learning activities;
(2) negotiating the social norms of the classroom.

Items:
4. (+)
10. (+)
16. (+)
22. (+)
33. (+)
36. (+)
40. (+)
V. STUDENT NEGOTIATION SCALE (SN)

This scale is concerned with negotiation amongst students. The scale has been designed to measure students’ perceptions of the extent to which they interact verbally with other students for the purpose of building their scientific knowledge within the consensual domain of the classroom. From a constructivist perspective, the classroom environment should not require students to learn in social isolation from other students or to regard the teacher or textbook as the main arbiter of what counts as viable scientific knowledge. Rather, the classroom environment should be concerned with engaging students in opportunities: (1) to explain and justify their newly developing ideas to other students; (2) to make sense of other students’ ideas and reflect on the viability of their ideas; (3) to reflect critically on the viability of their own ideas.

Items:
5. (+) 11. (+) 17. (+) 23. (+) 28. (+) 34. (+) 41. (+)

VI. STUDENT ATTITUDE (SA)

This scale has been included to provide a measure of the concurrent validity of the CLEQ. The attitude scale has been used extensively in research on science laboratory classes, and has an established reliability. The scale measures student attitudes to important aspects of the classroom environment, including: (1) their anticipation to the activities; (2) their sense of worthwhileness of the activities; (3) the impact of the activities on student interest, enjoyment and understanding.

Items:
6. (+) 29. (-) 12. (+) 35. (-) 18. (+) 42. (-) 24. (+)
### APPENDIX A2

#### SCIENCE CLASSROOM LEARNING ENVIRONMENT QUESTIONNAIRE

### SCORES – PARTICIPANT CALCULATIONS

<table>
<thead>
<tr>
<th>Personal Relevance (PR)</th>
<th>PBL</th>
<th>Historical PBL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beth Dana Emma Mark</td>
<td>Beth Dana Emma Mark</td>
</tr>
<tr>
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<td>4   5   3   4</td>
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<td>3   4   4   3</td>
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<td>4   5   3   4</td>
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<td>3   5   3   4</td>
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<tr>
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<td><strong>34</strong></td>
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<table>
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<th>Scientific Uncertainty (SU)</th>
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<td>2   2   3   3</td>
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<td>4   5   5   4</td>
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<td>5   5   5   4</td>
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<td>5   5   4   4</td>
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<td>Dana</td>
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<td><strong>Student</strong></td>
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<td><strong>Negotiation</strong></td>
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<td></td>
<td>42 n</td>
<td>3</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>23</td>
<td>27</td>
</tr>
</tbody>
</table>

p=positively scored; n=negatively scored
APPENDIX B

SEIMI-STRUCTURED INDIVIDUAL INTERVIEW QUESTION

Pre historical PBL Lesson background questions

1. What subject(s) do you teach?
2. What led you to learn about PBL instruction?

Pre and Post historical PBL lesson interview questions

3. How does the PBL lesson engage students?
4. In what ways was the PBL lesson geared toward student interests?
5. What view of science does the PBL lesson help to promote?
6. How is the direction of student learning decided?
7. In what ways, if any, are students given choices during the PBL lesson?
8. Is student-student discussion and reflection incorporated in the PBL lesson? If yes, how? If no, why not?
9. What were some reactions (positive and negative) of students throughout the PBL lesson?

Post historical PBL lesson interview questions

10. How was using a historical approach different?
11. What do you see as the advantages and disadvantages of using history as the context of learning?
APPENDIX C

CONSTRUCTIVIST CLASSROOM OBSERVATION FORM

Constructivist Classroom Observation Form (CCOF) developed by John Pecore

Overview
The CCOF was developed by modifying the Differentiated Classroom Observation Scale (DCOS) Protocol developed by Cassady, Speris, Adams, Cross, Dixon, and Pierce (2004). The goal when using the CCOF is to characterize a teacher’s classroom learning environment with respect to constructivist learning. The form is divided into three sections: a table for scoring learning activities and behaviors, a chart for describing both teacher and student actions, and a series of lines for writing additional field notes.

Header Information
The header of the form provides a space for recording the name of the teacher and school where the observation is taking place, the observation date, start time, and end time.

Scoring Learning Activities
In the first column record class information such as the class period, the type of class and the number of students working in groups as detailed in Table C-4.

Segment Scoring
The form consists of five scoring segment. Each segment may be defined by time like 10 minutes or by event such as introduction, exploration, explanation, or closure portion of the lesson.

• Learning Activity: For each scoring segment, record the instructional activity codes as described in Table C-1. Each segment may have multiple learning activities.
• Student Engagement: In the student engagement row, record the level of student engagement as defined by the percent, as defined in Table C-2, of students that appear to be actively learning/thinking for each segment.
• Constructivist Learning Principles: Using Table C-2, record the degree to which each of the six constructivist learning environment principles are evident during each segment of the observation.
• Learning Direction: In the learning direction row, record for each segment who makes the decisions about the learning activities as defined in Table C-2.
• Pedagogical Experience: Use the final row to record check if obstacles, limitations, and/or successes are observed as defined in Table C-3. Record a code in the same box. Provide additional details in the Actions or Notes section.

Teacher Student Actions
Use this chart to record the student and associate teacher actions.

Notes
This section can be used to record qualitative field notes during the observation.
<table>
<thead>
<tr>
<th>Class Information</th>
<th>Learning Activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>3</th>
<th>5</th>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>☐ R ☐ H ☐ I</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Sigr: ___</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Student Engagement</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Constructivist Learning Principles</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Learning Director</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pedagogical Experience</td>
<td>O</td>
<td>L</td>
<td>S</td>
<td>O</td>
<td>L</td>
</tr>
</tbody>
</table>

Teacher Actions | Student Actions

Notes:
Table C-1

*Instructional Activity Codes*

<table>
<thead>
<tr>
<th>Instructional Activity</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher reads problem</td>
<td>TP</td>
<td>Teacher reads problem to group of students</td>
</tr>
<tr>
<td>Students read the problem</td>
<td>SP</td>
<td>Students read the problem in small groups</td>
</tr>
<tr>
<td>Student groups</td>
<td>GD</td>
<td>Students in small groups discuss facts, need to know, action plan, and ideas/solutions</td>
</tr>
<tr>
<td>Teacher interacting with individual student</td>
<td>TIS</td>
<td>Teacher working with/talking to/helping individual student</td>
</tr>
<tr>
<td>Teacher interacting with small group</td>
<td>TIG</td>
<td>Teacher working with/talking to/helping small group of students</td>
</tr>
<tr>
<td>Technology use-students</td>
<td>TS</td>
<td>Technology being used by students for related learning activities (e.g., computer)</td>
</tr>
<tr>
<td>Other resources use - students</td>
<td>NTS</td>
<td>Other resources provided by teacher for related learning activities (e.g., books; teacher sheets)</td>
</tr>
<tr>
<td>Student presentation</td>
<td>SP</td>
<td>Student(s) presenting information to the class (either planned presentation or on-demand task)</td>
</tr>
<tr>
<td>Demonstration by teacher</td>
<td>D</td>
<td>Teacher demonstrating a procedure to the class (e.g., how to draw a classification scheme)</td>
</tr>
<tr>
<td>Questioning by teacher</td>
<td>Q</td>
<td>Teacher asking question of student(s) in group setting</td>
</tr>
<tr>
<td>Student responding</td>
<td>SR</td>
<td>Student(s) answering questions posed by teacher (choral response included in this category)</td>
</tr>
<tr>
<td>Manipulative</td>
<td>M</td>
<td>Student(s) working with concrete materials to illustrate abstract concepts (e.g., visual aids)</td>
</tr>
<tr>
<td>Seat work - individual</td>
<td>SWI</td>
<td>Student(s) working at desk on academic materials (independently)</td>
</tr>
<tr>
<td>Seat work - group based</td>
<td>SWG</td>
<td>Student(s) working at desk on academic materials (groups)</td>
</tr>
<tr>
<td>Cooperative learning</td>
<td>CL</td>
<td>Students working in a planned cooperative structure to complete a task.</td>
</tr>
<tr>
<td>Teacher interacting with individual student</td>
<td>TIS</td>
<td>Teacher working with/talking to/helping individual student</td>
</tr>
<tr>
<td>Teacher interacting with small group</td>
<td>TIG</td>
<td>Teacher working with/talking to/helping small group of students</td>
</tr>
<tr>
<td>Technology use - teacher</td>
<td>TT</td>
<td>Technology being used by the teacher for presenting instructional content</td>
</tr>
<tr>
<td>Assessment activity</td>
<td>A</td>
<td>Student(s) engaged in a formalized assessment activity (e.g., test; performance)</td>
</tr>
<tr>
<td>Teacher directed discussion</td>
<td>TDD</td>
<td>Teacher facilitates a whole class discussion</td>
</tr>
<tr>
<td>Teacher lecture</td>
<td>TL</td>
<td>Teacher provides lecture / students take notes</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>List “other” activities</td>
</tr>
</tbody>
</table>
Table C-2  
*Student Engagement, Learning Environment Principles, & “Learning Director”*

These are global ratings for each 10-minute segments. Thus, each segment will have only one rating of reach of these domains, the rating that is most representative of that time period for that group.

<table>
<thead>
<tr>
<th>Student Engagement (active learning/thinking)</th>
<th>Learning Environment Principles</th>
<th>“Learning Director”</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Very low engagement = 20% or fewer of students engaged in learning</td>
<td>PR - Personal Relevance SU - Scientific Uncertainty CV - Critical Voice SC - Shared Control SN - Student Negotiation SA - Student Attitude</td>
<td>Who directs the learning, or makes the decisions about the learning activities.</td>
</tr>
<tr>
<td>2 – Low engagement = 21 – 40% of students engaged in learning</td>
<td>Ratings are made in each segment following the given scale:</td>
<td>Use the following scale for making your segment ratings for the identified groups:</td>
</tr>
<tr>
<td>3 – Moderate engagement = 41 – 60% of students engaged in learning</td>
<td>1 – Not evident / negative 2 – Somewhat Evident 3 – Evident / neutral 4 – Represented 5 – Well-represented / positive</td>
<td>1 – Teacher directs all learning. 2 – Teacher directs most learning. 3 – Teacher and student share learning decisions 4 – Student directs most learning 5 – Student directs all learning</td>
</tr>
<tr>
<td>4 – High engagement = 61 – 80% of students engaged in learning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 – Very high engagement = 81% or more students engaged in learning</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

Table C-3  
*Pedagogical Experiences*

S – Successes = Record specific successes observed  
O – Obstacles = Record specific obstacles encountered  
L – Limitations = Note specific limitations

---

Table C-4  
*Class Information*

Period: ____ = what period (time of day) the class is taught.  
R – regular; H – honors; I – inclusion = Type of biology class  
# S/gr: ____ = Number of students per group
APPENDIX D

CASE PROBLEM BLUEPRINT PLANNING FORM

<table>
<thead>
<tr>
<th>PROBLEM BLUEPRINT PLANNING FORM</th>
<th>CASE: CLASSIFYING KINGDOMS</th>
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</thead>
<tbody>
<tr>
<td><strong>NO OBJECTIVE</strong></td>
<td><strong>2.3 VIABLE HYPOTHESES</strong></td>
</tr>
<tr>
<td>1.01: Identifying biological problems and questions that can be answered through scientific investigations.</td>
<td>Organisms should be classified based on Cope's evolutionary relationship.</td>
</tr>
<tr>
<td>1.03: Formulate and revise scientific explanations and models of biological phenomena using logic and evidence.</td>
<td>Whittaker maintains a functional classification based on organisms role in an ecosystem (producer, consumer, or decomposer).</td>
</tr>
<tr>
<td>4.01: Classification of organisms.</td>
<td>Monophyletic kingdom contains closely related organisms.</td>
</tr>
</tbody>
</table>

**PROBLEM**

In 1956, H. F. Cope introduced a four-kingdom classification schema where each kingdom is more closely related to one another than to any member of the other kingdoms (monophyletic). By contrast, in a polyphyletic kingdom, some organisms would be more closely related to some members of the other kingdoms than to some members of their own. Whittaker argued that ecologists had a functional classification system based upon the roles (producer, consumer, and decomposer) that organisms play in the ecosystem. As a taxonomist, you have been asked to give your expert opinion on classification systems at an upcoming conference to settle the debate on how to classify living things by unearthing a historical timeline.

**Note:** This lesson contains excerpts copied with permission from Hager, Allehin, & Singer (1996).
PROBLEM BLUEPRINT PLANNING FORM

ROLE: Taxonomist

SETTING: Library

TIME FRAME: 1956

CHALLENGE/OBJECTIVE: gain knowledge of the five-kingdom classification, its formation for classifying living things, and where biologists disagree.

PRESENTATION FLOW / "CYCLES"

1. Give problem to students
2. Students generate facts list (10 min. - focus on key facts)
3. Students list need to knows (10 min. - focus on priority needs)
4. Students research information (40 min.)
5. Students revisit need to knows
6. Answer problem question by

SOURCE OF FACTS DURING CASE PRESENTATION

Problem Statement

CASE: CLASSIFYING KINGDOMS

GENERAL NOTES

In 1956, H. F. Copeland introduced a four-kingdom classification with a new kingdom Protista for all bacteria and a kingdom Protoplast which included various algae, protozoans, and fungi. Each kingdom in Copeland's classification scheme were more closely related to one another than to any members of different kingdoms. The technical term for such a group is monophyletic. By contrast, in a polyphyletic kingdom some organisms would be more closely related to some members of other kingdoms than to some members of their own. Most taxonomists insist on monophyletic groups because they accurately reflect evolutionary relationships.

Whittaker, however, argued that ecologists already had a functional classification system based upon the roles that organisms play in an ecosystem. Although the groups overlap a bit, organisms can generally be classified as producers, consumers, and decomposers. Plants are producers, animals are consumers, and fungi are decomposers. According to Whittaker, ecological function provided a coherent basis for classifying most organisms that biologists study. This ecological classification system reflected three major branches on the evolutionary tree. Despite the ecological and evolutionary justifications for the three divisions, the system had some serious problems. One problem involved including bacteria in kingdom Fungi which makes ecological sense but not evolutionary sense. This other involved more complex unicellular organisms such as algae and protozoans. These creatures are ecologically and phylogenetically diverse.

RESOURCES FOR LEARNING ISSUES

Copeland's classification system
Whittaker's classification system
What is the difference between monophyletic and polyphyletic? Is one preferable over the other?
What does Copeland's four system classification look like?
What sorts of things help scientists determine evolutionary relationships?
What are producers, consumers, and decomposers?

LAB / ACTIVITY CORRELATES

Solving problems in the plant kingdom (attached)

FINAL PRODUCT (GRADED)

Draw a diagram depicting both Copeland's four-kingdom and Whittaker's three-kingdom classification schemes. What are the advantages and problems with each?

Note: This lesson contains excerpts copied with permission from Hagen, Alkhin, & Singer (1996).
Consider the similarities and differences among the organisms in the table. What are the problems with placing euglenoids and fungi (for example, mushrooms) in the plant kingdom? How well did Copeland’s four-kingdom system and Whittaker’s initial three-kingdom system solve these problems?

<table>
<thead>
<tr>
<th></th>
<th>Flowering Plant</th>
<th>Euglenoid*</th>
<th>Mushroom</th>
<th>Vertebrate Animal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell wall present</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Cell wall material</td>
<td>Cellulose</td>
<td>---</td>
<td>Chitin</td>
<td>---</td>
</tr>
<tr>
<td>Cells have flagella</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Some</td>
</tr>
<tr>
<td>Ingest food (heterotrophic)</td>
<td>No</td>
<td>Some</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Absorb food (heterotrophic)</td>
<td>No</td>
<td>Some</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Photosynthetic (autotrophic)</td>
<td>Yes</td>
<td>Some</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Ulitcellular organisms</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sexual reproduction</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Energy stored as starch</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

*Approximately 1,000 species, including the familiar green flagellate, Euglena viridis.

Note: This lesson contains excerpts copied with permission from Hugnet, Allchin, & Singer (1996).
PROBLEM BLUEPRINT PLANNING FORM

1.0.1: Identify biological problems and questions that can be answered through scientific investigations.
1.0.3: Formulate and revise scientific explanations and models of biological phenomena using logic and evidence.
4.0.1: Classification of organisms.

CASE: CLASSIFYING KINGDOMS

3.4 KEY FACTS

- Whittaker becomes an expert in taxonomic literature and the classification of unicellular organisms.
- Whittaker admits that unicellular organisms need their own kingdom called Protista.
- Whittaker's kingdom of Protista differs from Copeland's kingdom of the same name.
- Whittaker believes unicellular organisms formed a distinct evolutionary level or grade.
- Protista is a troublesome kingdom.

3.3 VIABLE HYPOTHESES

- Bacteria should be classified as Protista.
- Bacteria should be classified as Monera.

2.6 LEARNING AREAS

- Determine evolutionary relationships.
- Compare and contrast prokaryotic and eukaryotic organisms.
- Revision of scientific theories.

Note: This lesson contains excerpts copied with permission from Haeg, Alchin, & Singer (1996).
**Problem Blueprint Planning Form**

**General Notes**

In 1957 Whittaker immersed himself in the taxonomic literature, particularly the classification of unicellular organisms, which he knew little about. Two years later he admitted that these organisms could not simply be distributed among the kingdoms Plantae, Animalia, and Fungi. A new kingdom Protista would need to be created, but it would be defined quite differently than Copeland's kingdom of the same name. According to Whittaker, all protists must be unicellular. He divided this new kingdom into two parts. The higher protists included all nucleated (eukaryotic) unicellular organisms; protozoans, diatoms, euglenoids, and many other microscopic organisms. Nucleonucleated (prokaryotic) cells made up a lower subkingdom. This group included both the true bacteria and the cyanobacteria, an important group of photosynthetic prokaryotes often, but incorrectly, referred to as "blue-green algae." Unlike Copeland, Whittaker excluded all of the fungi, marine algae, and other multicellular organisms from kingdom Protista.

Whittaker justified his new kingdom because he believed that unicellular organisms formed a distinct evolutionary level or grade. During the distant past, unicellular organisms filled all three fundamental ecological roles—producers, consumers, and decomposers. Some of the unicellular lines have evolved into complex, multicellular organisms; so today most ecosystems are dominated by plants, animals, and fungi. But modern protists—the direct descendants of early unicellular organisms—still carry out these ecological roles in some ecosystems.

Drawing the boundaries of kingdom Protista was troublesome. Whittaker admitted that bacteria were structurally much simpler than the higher protists. Why not place the two groups in separate kingdoms? Such a decision would undermine the ecological basis for defining his kingdoms. Perhaps also for simplicity's sake, Whittaker declined to recognize a separate kingdom Monera—at least in 1959. The upper boundaries of kingdom Protista were also a little fuzzy. Many unicellular protists were closely related to multicellular plants, animals, or fungi. According to Whittaker, these boundary problems were inevitable. During the course of evolution some unicellular lineages remained relatively unchanged, while others split into closely related unicellular and multicellular groups. Knowing this, however, did not necessarily make the job of classification any easier. Throughout the 1960s, Whittaker wrestled with the problems of classifying the protists.

**Sources of Facts During Case Presentation**

**Problem Statement**

**Case: Classifying Kingdoms**

**Resources for Learning**

- What did Whittaker dislike about the four-system classification system proposed by Copeland? How did he want to change it?
- How did Whittaker move from the three-kingdom classification system to a four-kingdom classification system?

**Lab / Activity Correlates**

**Final Product (graded)**

Revise Whittaker's three-kingdom diagram to depict his four-kingdom diagram. Explain how Whittaker's and Copeland's four-kingdom diagrams differ.

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Note: This lesson contains excerpts copied with permission from Hugiel, Atkinson, & Singer (1996).
## PROBLEM BLUEPRINT PLANNING FORM

### NC OBJECTIVE

1.01: Identifying biological problems and questions that can be answered through scientific investigations.

1.03: Formulate and revise scientific explanations and models of biological phenomena using logic and evidence.

4.01: Classification of organisms.

### CASE: CLASSIFYING KINGDOMS

#### 3-4 KEY FACTS

- Whittaker convinced that unicellular organisms belong into two separate kingdoms.
- Prokaryotic cells lack a nucleus and most specialized organelles belonging in kingdom Monera.
- Eukaryotic, unicellular organisms, each with a nucleus and many specialized organelles, belonging in kingdom Protista.
- Organisms arranged hierarchically into three evolutionary levels and ecologically classified based on nutrition (producer, consumer, decomposer).
- While the five-kingdoms are based on fundamental natural relationships, important problems remain.

#### 2-3 VIABLE HYPOTHESES

- Brown and green algae belong in the Plantae kingdom.
- Prokaryotic cells lack a nucleus and most specialized organelles belonging in kingdom Monera.
- Eukaryotic, unicellular organisms, each with a nucleus and many specialized organelles, belonging in kingdom Protista.
- Some other theory or classification system.

#### 3-6 LEARNING AREAS

- Compare and contrast Eukaryotic kingdoms.
- Role of assumptions among scientific disciplines.

---

Whittaker became increasingly convinced that unicellular organisms must be divided into two separate kingdoms. He placed prokaryotic cells, which lack a true nucleus and most specialized organelles, into kingdom Monera. Eukaryotic, unicellular organisms, each with a nucleus and many specialized organelles, remained in kingdom Protista. All organisms could now be arranged hierarchically into three well-defined evolutionary levels. Upon this evolutionary branch, Whittaker superimposed his original ecological classification based on nutrition: producers, consumers, and decomposers. Whittaker's five-kingdoms seemed to be based upon fundamental natural relationships. Important problems remained with Whittaker's system.

Note: This lesson contains excerpted copies with permission from Hagen, Alchin, & Singer (1996).
PROBLEM BLUEPRINT PLANNING FORM

Problem Specifics
Role: Taxonomist
Setting: Library
Time Frame: 1969
Challenge/Outcome: gain knowledge of the five-kingdom classification, its formation for classifying living things, and where historically disease.

Presentation Flow / "Cycles"
1. Give problem to students
2. Students generate facts list (10 min. - focus on key facts)
3. Students list need to know (10 min. - focus on priority needs)
4. Students research information (40 min.)
5. Students revisit need to know
6. Modify Whitaker's classification diagram and identify important problems remaining.

Source of Facts During Case Presentation
Problem Statement

CASE: CLASSIFYING KINGDOMS

General Notes
Whittaker became increasingly convinced that unicellular organisms must be divided into two separate kingdoms. He placed prokaryotic cells, which lack a true nucleus and most specialized organelles, into kingdom Monera. Eukaryotic, unicellular organisms, each with a nucleus and many specialized organelles, remained in kingdom Protista. Endosymbiosis was only a provisional theory in 1966, but it certainly strengthened Whitaker's five-kingdom system. All organisms could now be arranged hierarchically into three well-defined evolutionary levels: prokaryotic organisms (kingdom Monera), eukaryotic, unicellular organisms (kingdom Protista), and eukaryotic, multicellular organisms (kingdom Plantae, Animalia, and Fungi). Upon this evolutionary hierarchy, Whitaker superimposed his original ecological classification based on nutrition: producers, consumers, and decomposers. Whitaker's five-kingdoms seemed to be based upon fundamental natural relationships.

Important problems remained with Whitaker's system. For example, what was to be done with the green algae (Chlorophyta), an important group of aquatic producers whose ancestors also gave rise to all land plants? The green algae (approximately 7,000 species) include both unicellular and multicellular forms. Do they belong in kingdom Plantae or kingdom Protista? Because they are so closely related to higher plants, Whitaker placed the green algae in kingdom Plantae - a decision that remains controversial.

Equally controversial was his decision to place the red algae (Rhodophyta) and brown algae (Phaeophyta) in the plant kingdom. He reasoned that even though these large, multicellular seaweeds are not closely related to other plants, they play the same ecological role - they are "functional plants" in many marine ecosystems. Furthermore, because of their size and complexity, they do not fit the unicellular characteristics that Whitaker used to define his kingdom Protista.

Lab / Activity Correlates
Where to place green and brown algae (attached)
http://www.ucmp.berkeley.edu/help/platteform.html (Website with information on the various taxonomic groupings)

Final Product (graded)
Revise Whitaker's four classification diagram into a five classification diagram and identify remaining important problems.

Resources for Learning Issues
- How/Why did Whittaker revise his four-kingdom system? What does his five-kingdom system look like?
- What are some problems with Whitaker's five-kingdom system?
- What is a protozoa? What characteristics do protozoa share? In what ways do they differ?
- What is the difference between prokaryotic and eukaryotic organisms?
- What characteristics of Brown and Green Algae make it difficult to classify?

Note: This lesson contains excerpts copied with permission from Hagen, Alchin, & Singer (1996).
Consider characteristics of the groups in the table. What characteristics could be used to place all three groups into the plant kingdom? On what basis could you exclude the green algae from the plant kingdom? On what basis could you exclude the brown algae?

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Flowering Plants</th>
<th>Green Algae</th>
<th>Brown Algae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose in cell wall</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Forms of chlorophyll</td>
<td>a and b</td>
<td>a and b</td>
<td>a and c</td>
</tr>
<tr>
<td>Energy stored in starch</td>
<td>Yes</td>
<td>Yes</td>
<td>no</td>
</tr>
<tr>
<td>Vascular tissue</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Multicellular</td>
<td>Yes</td>
<td>Some</td>
<td>Yes</td>
</tr>
<tr>
<td>Cells with flagella</td>
<td>No</td>
<td>Some</td>
<td>Reproductive cells</td>
</tr>
<tr>
<td>Habitat</td>
<td>Mostly terrestrial</td>
<td>Mostly freshwater</td>
<td>Mostly marine</td>
</tr>
</tbody>
</table>

Note: This lesson contains excerpts copied with permission from Hagen, Alchin, & Singer (1996).
<table>
<thead>
<tr>
<th>OBJECTIVE</th>
<th>KEY FACTS</th>
<th>Viable Hypotheses</th>
<th>Learning Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.01: Identifying biological problems and questions that can be answered through scientific investigations.</td>
<td>Classification system should reflect both ecological principles and evolutionary relationships.</td>
<td>Archaeobacteria should be a sixth kingdom.</td>
<td>Revision of scientific theories.</td>
</tr>
<tr>
<td>1.03: Formulate and revise scientific explanations and models of biological phenomena using logic and evidence.</td>
<td>Classification system must be convenient to use by students and biologists.</td>
<td>A radical classification restructuring is in order.</td>
<td>Six kingdom classification scheme.</td>
</tr>
<tr>
<td>4.01: Classification of organisms.</td>
<td>A five-kingdom system is reasonable, but compromises taxonomic principles and contains ambiguities.</td>
<td>Carl Woese studies archaeobacteria, unusual prokaryotes, which need to be classified.</td>
<td>Some other theory or classification system.</td>
</tr>
</tbody>
</table>

Whittaker struggled with the conflicting demands of a system that would reflect important ecological principles while still accurately portraying evolutionary relationships. Just as important was the demand that the system be convenient to use, both by student and professional biologist. A five-kingdom system was more reasonable, but it meant compromising some well-established taxonomic principles and accepting many ambiguities. Carl Woese spent his career studying several unusual groups of prokaryotes referred to as the archaeobacteria. There is an ongoing debate over the status of these unusual prokaryotes meaning that a system of classification, like all scientific theories, is open to revision. How would you revise Whittaker’s five kingdoms?

Note: The text contains excerpts copied with permission from Hogen, Aller, & Singer (1996).
Whittaker realized that a plant kingdom including the seaweeds would be polyphyletic. The shared similarity is anatomical roles between land plants and seaweeds seemed too compelling to ignore, however. As an ecologist, Whittaker was willing to accept a polyphyletic plant kingdom, but most botanists found this unacceptable. They modified Whittaker’s system by placing the red and brown algae into kingdom Protista—a decision that makes this kingdom a hodgepodge of unicellular and multicellular organisms.

Whittaker was aware of the problems facing his five-kingdom proposal, but struggled with the conflicting demands of a system that would reflect important ecological principles while still accurately portraying evolutionary relationships. Just as important was the demand that the system be convenient to use, both by students and professional biologists. One critic, for example, claimed that a phylogenetic classification of species would require 20 separate kingdoms. Such a system might accurately reflect evolutionary history, but Whittaker pointed out that it would be needlessly cumbersome. A five-kingdom system was more reasonable, but it meant compromising some well-established taxonomic principles and accepting many ambiguities.

Curt W. Woese spent his career studying several unusual groups of prokaryotes referred to as the archaeabacteria. These organisms have fundamentally different molecular, biochemical, and ecological characteristics than other bacteria. The archaeabacteria are intriguing because they often exist in extreme habitats characterized by high temperatures, high salinity, and high acidity. Largely due to the work of Woese and his colleagues, most biologists now recognize the archaeabacteria as a separate subkingdom. Woese, however, believes that a more radical restructuring is in order. According to Woese, archaeabacteria are so different from all other organisms that they should be placed in a separate taxonomic group. He would erect a new system with three superkingdoms or “domains.” Archeae (archaeabacteria), Bacteria (all other bacteria), and Eukarya (all eukaryotic organisms). Although most biology textbooks ignore this proposal, a few new place the archaeabacteria into a sixth kingdom. The ongoing debate over the status of these unusual prokaryotes serves to warn us that systems of classification, like all scientific theories, are open to revision.

Note: This lesson contains excerpts copied with permission from Hagan, Alchin, & Singer (1996).
### PROBLEM BLUEPRINT PLANNING FORM

**CASE: CLASSIFYING KINGDOMS**

<table>
<thead>
<tr>
<th>Assessment Measure</th>
<th>Scoring</th>
<th>Out Of</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performances: Students should show that they can collaborate as a group to be finished on time</td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Processes: Student Assessment sheets should be completed for each student expressing the part that each student played in reaching the conclusion.</td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Comprehension: In writing and discussion students should show an understanding of classification kingdoms. They should be able to present an explanation for a five (or six or seven) classification scheme and associated problems.</td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td><strong>Product:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Diagram depicts the four and three-kingdom schemes; advantages and problems with each are listed – 10</td>
<td></td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2. Modify the three-kingdom diagram to depict Whittaker’s four-kingdom scheme; explain how Whittaker and Copeland’s schemes differ – 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Revise Whittaker’s four-kingdom diagram into a five-kingdom scheme and identify problems – 15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Construct a six-kingdom classification system; provide your thoughts on such a scheme - 15</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Final Score** 100

---

Note: This lesson contains excerpts copied with permission from Hager, Alchin, & Singer (1996).
APPENDIX E

COPYRIGHT PERMISSION LETTER

John Pecore
Wake Forest University
Department of Education
PO Box 7266
Winston-Salem, NC 27109

October 8, 2009

Dr. Joel Hagen
Radford University
Department of Biology Reed 306
801 East Main St.
Radford, VA 24142

Dear Dr. Hagen:

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Joel Hagen, Ph.D.

Date: 10/8/09