A CONTENT ANALYSIS OF VIRTUAL SCIENCE LABS
IN CYBER CHARTER SCHOOLS

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by
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ABSTRACT

This research studied the labs being used in cyber charter schools. Using a purposive sampling technique this study looked for identifiable markers that have the potential to engage learners in scientific practices and crosscutting concepts in middle school cyber charter schools in Pennsylvania. Markers for support from constructivist instructional design are identified and described. The framework for observing the virtual labs was formed from science practices and crosscutting concepts outlined in The Next Generation Science Standards (NGSS) and design principles from constructivism. Crosscutting concepts are the foundational concepts that cut across science disciplines. The NGSS are based on the National Research Council’s 2012 A Framework for K-12 Science Education. Core ideas are the third foundation of science and are not included in this dissertation as they have been studied in several other science labs (see Pyatt & Sims, 2011; Van Joolingen, De Jong, & Dimitrakopouluo, 2007). Scientific practices are espoused in the Next Generation Science Standards (NGSS) as competencies that all students should experience to understand how science works. Constructivist support features will guide the identification of design features that could be present in the labs.

Specifically an ethnographic, directed content analysis was used to frame findings. The goal of content analysis “always involves relating or comparing findings to some standard, norm, or theory” (Carney, 1972, p. 5). This research used the NGSS as standards and the constructivist design supports as the practical application of constructivist learning theory. The directed nature of this content analysis allowed for emergent categories. Ethnographic content analysis (ECA) can be considered ‘etic’
because it is not aimed at “understanding informants from their own perspective” (Smith, Sells, & Clevenger, 1994, p. 2). An ECA forges a bridge between traditional content analysis and more ethnographic techniques. Berelson (1952) and Carney (1972) characterized traditional content analysis as quantitative and objective. An ECA approach focuses on the reflexivity of the research design while allowing for emergent data categories and narrative descriptions (Altheide, 1987). ECA differs from traditional content analysis because of the reflexive and highly interactive nature of the investigator, concepts, data collection, and analysis (Altheide, 1987, p. 68). Directed content analysis was selected because there is previous research and design principles for science labs, both virtual and traditional, but none of the extant literature found specifically looked at the labs being used in cyber charter schools or worked with K-12 students who were receiving their education primarily in an online environment. Interviews conducted with eight teachers from five cyber charter schools revealed that there is not a uniform laboratory experience for students and it does not always match the existing definitions for what a science lab is. Interviews with teachers revealed that there are a variety of innovative ways that teachers and schools have used to engage students with labs. The sample size of 20 virtual labs (4 from each of 5 cyber charter schools) was intended to provide an in-depth and targeted picture of the phenomena under study. Labs were selected based on a variety of factors. Preference was given to labs that the teacher used, that led to a wide range of core ideas selected, and that were from multiple software systems.

A framework was created to serve as the preliminary guide of the relationships between and amongst the categories. This framework was built from the two foundations
of the NGSS and design principles from constructivism. The framework is used as a starting point for the analysis of the content of the labs. In being consistent with directed content analysis, the constructs gained from previous research are used both to orient the current study and to extend the knowledge around an existing theory (Hsieh & Shannon, 2005).

The results of this study identified a significant amount of variation in the science labs that students complete in cyber charter schools. Eight themes emerged from the teacher interviews that spoke to the range of expectations, support, and curricula in cyber charter schools. The themes are (1) the design of the labs; (2) teacher dedication and improvisation; (3) teacher availability to students; (4) communication practices; (5) parental expectations from the school; (6) challenges with the virtual labs; (7) willingness to allow revisions and give detailed feedback to students; and (8) teacher definitions of labs in the virtual setting. The science practices identified by the NGSS as central to the practice of science are all identified in at least one of the labs analyzed. However, as a whole the labs met some of the science practices more than others. 40% of the labs allowed students to ask research questions, 30% of the labs had prompts that allow engaging in argument from evidence, and 10% of the labs encouraged students to communicate and discuss the results of their labs. Many of the crosscutting concepts identified in the labs were implicit (34%) rather than explicit (19%). Therefore, the concept was not made clear during analysis of the labs. Quinn et al. (2012) stress the importance of making these concepts explicit to students. All of the labs had some constructivist design features/markers of constructivist learning environments. Markers that were particularly present in the labs were having some level of descriptive sequence
for the students to follow in the lab (95%), controlling confounding variables for the students (80%) and giving the students some level of control/independence over the lab (75%). The constructivist design components lacking were communication features to promote communication between instructors and peers (10%), reflective and metacognitive scaffolds (25%), and having authentic activities (45%). The labs were particularly lacking in asking students for their prior knowledge (25%), acknowledging the complexity of empirical work for students (5%), or having students reflect on the empirical design (5%). Many of the labs had both ill (50%) and well-structured (70%) problems, experiments (40%) and observations (70%) all in the same lab. As a result of this research emergent categories related to the context of cyber charter schools such as engaging with parents, reducing navigation windows, and being ‘text-lite’ for students came from studying the labs. The knowledge gained from this study is that (a) more is known about the context in which students complete their virtual labs; (b) the structure and details of the virtual labs have been deeply described; and (c) emerging relationships between important features of a virtual lab from the student perspective are postulated.

For cyber charter school students who do not have the option of face-to-face physical labs, the virtual labs should provide an equivalent educational experience. This research extends the conversation on whether virtual lab activities have the potential to provide this equivalent educational experience.
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Chapter 1

Introduction

The growth and proliferation of cyber charter schools over the past decade and a half has resulted in 206,000 students enrolled in cyber charter schools during the 2013-2014 school year (Molnar et al., 2014). The first cyber charter school in Pennsylvania was the SusQ-Cyber charter school started in 1998 (SusQ, 2012). As of October 6th, 2014 there were fourteen Pennsylvania cyber charter schools. In the 2012-2013 school year there were just over 35,000 students enrolled in sixteen cyber charter schools across Pennsylvania (Jack, Sludden, & Schott, 2013). Taking away the enrollment for the two cyber charters that no longer exist brings the enrollment figure to just under 35,000.

A cyber charter school is a form of distance education. Distance education has evolved from primarily one-way communication to two-way communication and interactions between members (Sumner, 2000). Cyber charter schools are a relatively recent innovation in the public school choice landscape. Pennsylvania has been among the leaders in states adopting cyber charter schools (Mann & Barkauskas, 2014). Cyber charter schools have more flexibility to be innovative in their structure and function for public schooling. However, cyber charters still need to meet standards and regulations imposed by the chartering agency (Kim, Kim, & Karimi, 2012).

A defining feature of cyber charter schools is that students receive the majority of their instruction in an online environment. Consequentially, there are no longer geographic barriers separating students into different schools. The approving agency that grants a cyber charter school its charter varies across state lines. All of the cyber charter schools in this study operate independently of traditional brick-and-mortar schools. There is a mix of cyber charter schools
operated by a company that also runs “for-profit education management organizations (EMOs) or a nonprofit, community-based organization” (Carr-Chellman & Marsh, 2008, p. 52). The former tends to be chains of cyber charters and the latter smaller local schools. Schools can choose to use a purchased curriculum or can have the teachers design the curriculum.

One of the promises of cyber charter schools is that they are tailored for individualized learning (Barbour & Reeves, 2009). The schools can differentiate instruction and be more flexible in the time and delivery of instruction. However, even with more individualized instruction, students still use the same curriculum and materials for their studies as their peers and must reach the same academic milestones.

All students enrolled in public school must take science classes in order to earn a high school diploma. A valuable part of many science classes are laboratory investigations (Hofstein & Lunetta, 2004; Hofstein & Mamlok-Naaman, 2007; Ma & Nickerson, 2006). *America’s Lab Report: Investigations in High School Science* defines science labs: “laboratory experiences provide opportunities for students to interact directly with the material world (or with data drawn from the material world), using the tools, data collection techniques, models, and theories of science.” (Singer, Hilton, & Schweingruber, 2005, p. 3). This definition dictates that students should be directly interacting with material (either physical or virtual) using science techniques. This definition is implied to be written in the context of traditional face-to-face classrooms. It is not known if the virtual labs used in cyber charter schools have students interact with material in ways that reflect the ways scientists do when conducting experiments/labs.

Due to the geographic distance between teacher and students and among students in cyber charter schools, students are experiencing their laboratory investigations in a variety of ways. Through discussions with cyber charter schools it was revealed that the schools are not
using only virtual labs the delivery choice for labs. The Pennsylvania Science Standards shown in Appendix C show the middle school standards that can be met through laboratory investigations. The variety of delivery mechanisms for engaging students with lab experiences that could meet the PA standards or NGSS practices range from virtual labs, physical kits that are sent to students’ homes, webcams that broadcast the teachers completing the labs for students and asking them questions, teachers creating or editing existing YouTube videos into laboratory sequences, students using common household materials to conduct some investigations, or teachers take their classes on a virtual fieldtrip. All of the schools selected in this study use virtual labs with software simulations. Some of them also use other delivery mechanisms such as webcams and virtual field trips, but these were not identified as the sample for this study to keep the delivery model consistent.

In a virtual lab, students can perform many of the same tasks that they would perform in a physical lab. However, the function of the environment necessarily changes the structure of the labs. A virtual science lab depends on computer simulations and programming to run properly. There are several virtual labs available today such as the web-based inquiry science environment (WISE), GO-LAB, PhET™, Smart Science Online Science Labs, and ExploreLearning, among others. The cyber charter schools in Pennsylvania employ some of these labs but also use labs created by curriculum providers. Two of the more popular curriculum providers in cyber charter schools are K-12 Inc. and Florida Virtual School.

One of the agreed upon goals of science instruction and, specifically laboratory investigations, are that they present an inquiry experience for students. Inquiry can be conceptualized as: allowing students to work together, building on their prior knowledge and recognizing misconceptions, substantiating their conclusions and reasoning, and divulging their
findings with their teacher and peers (Wolf & Fraser, 2008). The NGSS add further support to using inquiry methods when they state, “students should develop an understanding of science as a whole – the wondering, investigating, questioning, data collecting, and analyzing” (NGSS: Appendix H, 2013).

Recently, there has been a debate within the science education community on whether the terms “inquiry” or “practices” should be used in describing students’ active investigation with science. The word ‘inquiry’ has been used by many different researchers and lacks a salient definition. The NRC Framework advises the term practices to provide more specificity as to what exactly the scientific practices are that students should be doing. Inquiry is still used in journal articles (Sharples et al., 2014), however use of the word ‘practices’ is in alignment with the most recent NGSS science standards. The word practices connotes a systemic view of science that extends beyond terms like variables to include modeling or communicating results. Practices also eliminates the idea that there is one ideal approach to doing science depending on how much is known about a phenomenon. In this study, the phrase ‘science practices’ will be used to describe the expectation for students in the virtual labs rather than ‘scientific inquiry’. However, virtually all of the previously cited studies have used the term ‘scientific inquiry’ as the ‘science practices’ term was not yet established and thus scientific inquiry will be used if the previous researchers described their work using this term.

Presenting students with experiences to explore science practices and opportunities to build their understanding of science may increase the likelihood that they will develop scientific literacy. The National Research Council states that “promoting scientific literacy among all of the nation’s people is a democratic ideal worth of focused attention, significant resources, and continuing effort” (Quinn, Schweingruber, & Keller, 2012, p. 277). Students in cyber charter
schools should have an equitable opportunity to develop their scientific literacy. In addition, students exposed to science courses in schools increases their likelihood of choosing a STEM career path (Wang, 2013). Previous studies have shown that students gain this career interest in secondary school (Maltese & Tai, 2011) and that scientific inquiry labs improve students’ attitudes around science (Wolf & Fraser, 2008).

**Problem Statement**

There is no shortage of literature investigating the use of virtual science software and hands-on labs in traditional brick-and-mortar K-12 classrooms. Researchers have attempted to compare the effects of physical versus virtual labs on student understanding of content (Klahr, Triona, & Williams, 2007; Zacharia & Olympiou, 2011) and attitudes of students in laboratory activities (Chen, Chang, Lai, & Tsai, 2014; Pyatt & Sims, 2011). The design and use of virtual science software and labs has also been investigated to design a framework for scaffolding scientific inquiry (Quintana et al., 2004), for shaping personally-meaningful inquiry that transcends formal learning boundaries (Sharples et al., 2014), and improving student learning and understanding (Svilha & Linn, 2012; Varma & Linn, 2012). Chen (2010) investigates what type of scientific reasoning is present in freely available physics virtual labs using a content analysis.

It is not known what labs are being used by middle school students in cyber charter science classrooms and if these labs have the potential to engage students in science practices and crosscutting concepts. Considering that becoming scientifically literate is a goal of the NGSS, and that laboratory investigations are designed to help achieve that goal, it is prudent to study the labs being used by cyber charter school students.
Cyber charter schools can choose to host synchronous sessions between instructors and students; these are primarily to lecture, demonstrate content and model activities that students complete asynchronously, or have students participate in a class (Roblyer, 2008). This study assumes that currently students are thus completing the majority of their labs independently of their peers and teacher. While online and computer-supported learning have become prominent feature in brick-and-mortar schools, students in cyber charter schools are receiving more of their instruction online than their traditional peers. In brick-and-mortar schools there are barriers to technology integration and these barriers exist even in quality examples of technology at the K-12 level (Hew & Brush, 2007). In a cyber charter school there are still barriers to effective use of technology such as the culture or attitudes around technology and artificial blocks on content and simulations. However, the other barriers that prevent technology use in brick-and-mortar schools such as having the resources and knowledge around using technology are less prevalent (Hew & Brush, 2007). According to Pennsylvania Law 1949 Act 14 every cyber charter school student is provided with a computer and internet stipend as part of their attendance (Pennsylvania General Assembly, 2015). Therefore, from the issue of resources alone cyber charter-school students are receiving more of their instruction through a computer than students in brick-and-mortar schools. This learning environment is different than it was in previous research on student experiences with virtual labs. This study takes a systems perspective on distance education that makes understanding the context and factors impacting the learning experience, such as the learning environment, worth studying (Moore & Kearsley, 2011). Understanding the potential these labs have to engage students in science practices is increasingly important. The problems addressed in this study are: “What labs are being used in the cyber charter schools selected for this study?”, and “What potential is there in the cyber charter-school labs to engage students in
Purpose Statement

The purpose of this study is to understand what type of science practices and crosscutting concepts have the potential to engage cyber charter-school students in science. Specifically, the labs will be observed and classified to look for identifiable markers that provide potential to engage students in science practices and crosscutting concepts. The motivation driving this research is that science labs are an important part of science education for students (Burkham, Lee, & Smerdon, 1997; Hofstein & Lunetta, 1982; Hofstein & Lunetta, 2004, Singer et al., 2005). Cyber charter schools use a variety of labs to meet the science laboratory experience and the potential of these labs to engage students in science practices and crosscutting concepts needs to be understood.

The laboratory experience for students in a cyber charter school has not been studied. An appropriate first step is to do a content analysis of the labs to describe the potential the labs have for engaging students in science practices and crosscutting concepts. The media for this study are the labs used by middle school science students at select Pennsylvania cyber charter schools. The cyber charter schools were selected based on their use of virtual labs at the middle school level and their willingness to participate in the study. This study explores new media as prior research used a content analysis to analyze widely available physics virtual labs for the type of reasoning, hypothetico-deductive or holistic, being presented to students (Chen, 2010). This sample was not of labs specifically used in a school. In addition, the student population of middle school students using the labs has not been extensively studied (Raish, Tang, & Carr-Chellman, 2012). This research provides an important contribution to the field by describing the ways that cyber charter
schools and teachers give students the opportunity to participate in labs, the science practices and crosscutting concepts identified in those labs and how these findings can contribute to the existing literature on middle school science labs and online learning. The entirety of the science labs that students access while they are completing the labs will be collected from the student perspective. In addition, interviews will be conducted with teachers using the labs to provide a description of the labs and how the teachers define the labs.

**Research Questions**

The research questions being addressed by this study are:

1. What are the variations of labs that are in the cyber charter schools included in this study?
2. Are there identifiable markers observed in the labs in cyber charter middle school classrooms that have the potential to engage students in science practices and crosscutting concepts for the students?
3. Are there constructivist design components used in the labs to support the potential the labs have to engage students in science practices and crosscutting concepts?

**Definitions of Terms**

**Content analysis.** A common analytic technique for looking at documents, discussions, or multimedia. Specifically, latent content analysis concerns itself with what a media is ‘talking about’ and interpreting what this means. (Graneheim & Lundman, 2004) and directed content analysis is used when there are already some theories and ideas surrounding a phenomenon (Hsieh & Shannon, 2005). Ethnographic content analysis is used to provide a narrative in addition to numbers and to inductively have categories emerge (Altheide, 1987).
**Constructivism.** “Assume that knowledge is individually constructed and socially co-constructed by learners based on their interpretations of experiences in the world…instruction should consist of experiences that facilitate knowledge construction” (Jonassen, p. 217, 1999).

**Core ideas.** Core ideas are used to allow “deep exploration of important concepts” and to “provide an organizational structure for the acquisition of new knowledge” (Quinn et al., 2012, p. 25)

**Crosscutting concepts.** These concepts are not unique to one domain of science, but rather cut across all fields of science and unite the disciplines (Quinn et al., 2012)

**Cyber Charter School.** A public school that is formed with a charter. Can be operated by an educational management organization (EMO) or through independent stakeholders. Able to draw students from across the state and receive tuition money for those students from the state as a traditional brick-and-mortar public or charter school would.

**Inquiry.** *Definition 1:* “Asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information” (NGSS, Appendix F, p. 1).

*Definition 2:* How scientists study the world, the activities students do to help them develop scientific content and process knowledge, and students in turn developing an understanding of what scientists actually do (NSTA position statement, p. 1).

**Scientific practices.** The components of science that are reflected in what scientists do. Scientific practices are very similar to scientific inquiry but emphases the actual experiences of scientists in the field (Pellegrino, Wilson, Koenig, & Beatty, 2014). All science fields use “data and evidence as the foundation for developing claims” (Quinn et al., 2012, p. 27). Practices also
involve using argumentation with evidence and being able to thoroughly analyze and critique one’s own knowledge and the knowledge of others (Quinn et al., 2012). Practices are thus more holistic than inquiry and include a more overall picture of what scientists do.

**Technology.** The definition includes the product – which is the tool of technology and the process – which is the information base of that technology (Peck & Dorricott, 1994).

**Virtual lab.** Labs that can be completed entirely on the computer. Often are designed to focus on scientific content with strategies to reduce failure, time wasted, and distractions for students (Chen, 2010).

**Importance of the Study**

According to McKenney and Reeves (2012) it is valuable to probe a problem prior to launching a full-fledged design study. This study is intended to serve as a valuable resource for future studies investigating and designing labs for students in cyber charter-schools. It is important to study, in detail, the science labs students are already completing. In addition, when there is not a lot known about a phenomena it is good practice to conduct qualitative exploratory research to gain a deeper understanding of the phenomenon. Feuer, Towne, and Shavelson (2002) eloquently state this when they say: “when a problem is poorly understood and plausible hypotheses are scant – as is the case in many areas of education” that qualitative methodologies “are necessary to describe complex phenomena, generate theoretical models, and reframe questions” (p. 8).

Chen (2010) has conducted a content analysis on virtual labs but this has been limited to physics labs that are widely available and have not been specified for use in a school. In addition, Chen (2010) looked at the labs to understand whether they are presenting inquiry holistically or hypothetico-deductive; not to assess their potential to engage students in science practices,
crosscutting concepts, or some of the constructivist design components present in the virtual labs. Kesidou and Roseman (2002) look more broadly at the curriculum being used in middle school science classrooms in traditional brick-and-mortar schools. Finally, German, Haskins, and Auls (1996) analyze how well traditional laboratory manuals have promoted inquiry for students. However, none of these studies have looked specifically at the labs being used in cyber charter-schools. Nor have any of these studies attempted to map labs to the framework of science practices and crosscutting concepts from the NGSS, NRC Framework, and recent studies of online science software using constructivism as a learning theory or design framework. Thus, this research adds new knowledge to the growing field of online K-12 education and provides a baseline from which other studies can build.

Limitations of the Study

Due to the qualitative nature of the study, the work does not intend to create generalizable claims or causal relationships. Since the sample is the labs students are using these are not limited to the ‘emic’ experiences of the participants (Altheide, 1987). Therefore, providing a ‘thick and rich’ description (Geertz, 1973) from the participant perspective is a limitation of this study. In addition, because only a select number of cyber charter schools will be included in this study, the labs that are being used at other cyber charter schools are not analyzed. This research describes part of what occurs in virtual labs in cyber charter schools but is not intended to be representative of ALL cyber charter schools. Data are collected to help contextualize the lab experience for the students in the flow of their whole educational experience, but this will not give insights into the perceptions, attitudes, or learning of the students. A goal of this research is to lay the foundation so that future research can begin to alleviate some of these limitations and
paint a more comprehensive picture of the complexities of learning science within the online K-12 setting.

Summary

Cyber charter schools are no longer considered a new option in the school choice movement in Pennsylvania. Approximately 35,000 students are receiving their education from these schools (Jack et al., 2013). The importance of sound science education leading to the development of a scientifically literate citizen able to understand complexities of science is a goal of the National Research Council and NGSS. These 35,000 students are receiving their science education in a manner that has not been systematically studied. The students and other interested stakeholders deserve to know if they are receiving a science education that has the potential to develop their science knowledge in a manner consistent with the NGSS. The goal of this research is to begin to paint the picture of the science practices, crosscutting concepts, and constructivist supports that the virtual labs students are using in cyber charter schools have the potential to engage students. This will be done through description, analysis, and situating these findings in the existing literature on virtual science labs.
Chapter 2

Review of Distance Education, Constructivism, and Science Learning

The goal of this literature review is to demonstrate familiarity with existing research related to distance education, cyber charter schools, scientific inquiry, constructivist learning environments, virtual labs, science practices, and crosscutting concepts. Literature reviews help to illuminate what has already been done in the field, identify possible avenues for further research, and understand various perspectives in the field. In addition, having a succinct literature review provides a framework for interpretation of results in the discussion section (Randolph, 2009). Ultimately, a literature review that is well done will lead the reader to: a deeper understanding of the problem, how the study relates to previous research, the need for the study, and the justification for its importance.

The first section of this chapter contains the literature review. This section is sequenced by reviewing the literature on distance education, cyber charter schools, and learning through media. This section provides background information necessary to understand the theoretical constructs used to shape the study.

The second section of this chapter contains the conceptual and theoretical frameworks. The theoretical framework is constructivism and the conceptual framework is science practices and crosscutting concepts diSessa and Cobb (2004 that developing a theory is crucial for human science field such as education. However, due to the lack of any one theory being able to account for all of the complexities in education, design, and learning; it becomes necessary to develop a comprehensive theoretical framework that can justify and validate a particular research topic. In this case, the theoretical framework used orients virtual science labs within broader themes in the
literature. The frameworks used in this chapter are intended to contextualize the research and provide an understanding for the ensuing results and discussion.

Constructivism is segmented into theoretical constructivism, constructivist learning environments, and constructivist design components. Constructivism as a theory focuses on explaining how people learn while constructivism as a design focuses on what features in a learning environment are essential for promoting a constructivist theory on how people learn. Constructivist designs foster active learning environments using scaffolds, reflection, metacognition, and authentic learning. The conceptual framework of science practices uses the theoretical framework to orient the study around exploring the potential that labs used in cyber charter-schools have to engage students with science practices and crosscutting concepts. A framework was developed to identify the potential markers that could be seen in the labs based on previous research and discussion around constructivist designs, science practices, and crosscutting concepts. To develop this framework, a synthesis of existing research and standards on scientific practices and crosscutting concepts was used. The framework is used as a reference point for the content analysis of the virtual labs in specific cyber charter schools.

**Literature Review**

**Distance education.** Without technology, distance education would not exist. Heidegger uses the instrumental definition of technology. In this sense “technology is a means to an end” and “technology is a human activity” (Heidegger, 2010, p. 101). Distance education of today uses modern technology like the internet to deliver courses; distance education courses of the past took advantage of more simplistic technologies such as mail.

According to Moore and Kearsley (2011) distance education is defined as: “teaching and planned learning in which teaching normally occurs in a different place from learning, requiring
communication through technologies as well as special institutional organization” (p. 2). This definition is valid for cyber charter schools. Previous distance education courses offered curriculum and materials through the mail, radio, television, and the computer (Sumner, 2000). Since that time the use of mobile devices has skyrocketed, and students can access materials and interact with their course through these devices (Ally, 2009). With the rapid development of information and communication technologies (ICTs) the landscape of education has been significantly altered. There are now online courses offered for students from kindergarten to senior citizens. Students who are enrolled in distance education courses need to learn in a remote system and learn how to use technology for formal learning activities (Moore & Kearsley, 2011).

One concern with distance education is the lack of quality in the courses exacerbated by ‘diploma mills’ (Noble, 1998). There are several standards and rubrics for evaluating distance education courses. For example, the Quality Matters Rubric has eight standards and a peer review process that online courses must pass if they are to receive approval (Hoffman, 2012). While this type of evaluation and accreditation process occurs at higher education levels, there is not an equivalent body to certify online courses used in K-12 schooling. Some states have begun to evaluate the online courses and curricula that cyber charter schools are using (Molnar et al., 2014). According to a report by the National Education Policy Center no organization has considered the Common Core standards in terms of applications to an online environment (Molnar et al., 2014). It is fair to say that no organization has looked at the NGSS through the lens of their appropriateness for use in an online environment. However, these are limited in scope and states have made little progress in monitoring the curriculum used at the K-12 level.

**Cyber charter schools.** A cyber charter school is a specialized model of distance education. Cyber charter schools emerged out of the charter school movement. The charter
school movement began in 1991 when Minnesota passed a charter school law (Ahn, 2011). These schools are created through a charter with the state and are expected to comply with fewer regulations than traditional brick-and-mortar schools (Huerta, Gonzalez, & d’Entremont, 2006). According to the Pennsylvania Department of Education (PDE), cyber charter schools have to comply with regulations that revolve around “nondiscrimination, health and safety and accountability” (2014, p. 1). Raish and Carr-Chellman (2015) note that cyber charter schools differ from traditional brick-and-mortar schools due to the following characteristics: students partake in educational activities primarily by using the internet, there are no geographic barriers to attending the school (within one state), teachers and students are separated geographically, and parents are expected “to take a more active role in their child’s schooling” (p. 60).

There are several potential benefits of cyber charters schools that focus on the potential of having a personalized learning environment for students. However, much of these perceived benefits are theoretical and not grounded in empirical research (Barbour & Reeves, 2009). The sparse evaluations of K-12 online courses have focused only on the design of the course and not the outcomes (Molnar et al., 2014).

According to a report by Miron and Urschel (2012), approximately 27% of cyber charter schools run by EMOs met AYP as compared to 52% of traditional public schools. In addition, schools operated by K12 Inc. (an EMO) scored below average for both math and reading during the 2010-2011 school year. Another study by Jack et al., (2013) looked at the school performance profile (SPP) for the eleven cyber charter schools in Pennsylvania who were able to have a SPP. A school performance profile is “intended to serve a variety of purposes including providing parents and the broader public with a tool to compare schools” (Jack et al., 2013, p. 2). All eleven of these schools had SPP scores that were below the state average of 77.2. The
average for the cyber charter schools was 44.7. A criticism of using the SPP score to evaluate school success and student performance is that it is correlated with socioeconomic status. However, cyber charter schools perform worse than the high-poverty traditional schools (Sludden & Westmaas, 2014). The research thus far shows that the majority of cyber charter schools are underperforming. There is limited empirical research looking at the effectiveness of cyber charter schools. One could argue that due to a shift in focus on innovations and novel pedagogical approaches that traditional measures of student success are not applicable to cyber charter schools.

Defenders of cyber charter schools contend that they are serving larger numbers of special needs children and a transient student population that has not connected with traditional brick-and-mortar schooling. Cyber charter schools are using innovative techniques to reach kids who have left traditional brick-and-mortar schools. Jack et al. (2013) looked at student mobility in Pennsylvania’s cyber charter schools. In the 2011-2012 school year the state average for transfer-in was 31% and for transfer-out was 27%. A transfer-in rate is the number of students that enroll after the beginning of the school year divided by the total number of students where a transfer-out rate is the number of students that left the school after the start of the school year divided by the total number of students. Only five cyber charter schools kept these records. Two of these schools had a much higher transfer-out rate than the average (41% and 55%). The other three schools were right at or slightly below the state average (25%, 21%, and 27%) (Jack et al., 2013). There are additional benefits of cyber charter schools such as the ability for students who were not being served by traditional schooling models to continue their education and offering school choice to students (Ahn, 2011).
This study does not systematically examine the entirety of the NGSS, it evaluates labs for their potential to engage students in science practices and crosscutting concepts for students. These standards need to be evaluated in an online environment.

The medium of instruction is not a factor in the learning outcomes for students but the design and context of that instruction is (Clark, 1994). From a systems perspective, the whole system interacts and affects the experiences of students in cyber charter-schools. Therefore, it is useful to explore the history and nature of online learning environments.

**Online learning.** Online learning is but the latest outcome of technological innovations used for distance education. Technology is intertwined in the history of online learning. Heidegger (2010) encourages one to consider the relationship they have with technology. For Heidegger, the true essence of technology is the world perspective that people take. The key to understanding how to use technology is to question the nature of technology, and *the* how and *the* why we are using it (Heidegger, 2010). By only conceiving of technology as a tool or as a process while ignoring the essence of philosophy reduces the system to isolated parts. This argument goes back to the time of Plato. Plato believed that the shift from memorizing and speaking to reading and writing can ruin the dialogic nature of speech and turn instruction one-sided (Feenberg, 2001). For him the relationship between teacher and pupil was paramount to the learning experience.

Throughout history, there have been efforts to curtail the importance of teachers through one-way technologies. Although these have failed in the past there are concerted efforts to make one of the solutions for the ‘cost disease’ in education the use of educational technology (Feenberg, 2001). The ‘cost disease’ is a concept explained in Bowen (2009) in which the actual cost of education cannot be trimmed significantly as it can in other industries. Education, like an
orchestra, is a labor-intensive process and this reduces the ability to lower the cost of education (Baumol, 2012). There is hope that online learning can reduce the cost burden of higher education (Deming, Goldin, Katz, & Yuchtman, 2015). However, the quality of online education needs to give students the equivalent experience as their peers in a traditional face-to-face classroom.

Online learning continues to grow at the K-12 level with 1,816,400 enrollments in the 2009-2010 school year in at least one online course. In the 2012-2013 school year 310,000 students were enrolled in full time online schools (iNACOL, 2013). The vast majority of distance education courses today are delivered online (iNACOL, 2013). The primary difference between distance education in an online environment and previous distance education courses is the speed at which communication can occur (Feenberg, 2001). The consistent developments in ICTs shorten the gap between peer-peer and peer-teacher communication.

The reduction in communication time increases the level of interaction possible in distance learning. Research on the cooperative learning model in online courses shows that students who experienced the CL model feel that they learned more (Kupczynski, Mundy, Goswami, & Meling, 2012). In science education online discussions can help students to understand science (Hoadley, 2000). Discussions and communication allow students to see different perspectives on a topic. It is difficult to have these discussions or promote rich online discussions (Hoadley, 2000). A central focus in this study is the design affordances built-in to foster peer-peer and peer-instructor communication.

There are design considerations that need to be made when online learning is used. For online learning to be successful “learning materials must be designed properly, with the students and learning in focus, and that adequate support must be provided” (Anderson, 2008).
Descriptions of indexicals and descriptives in linguistics clarify why design in an online learning environment is critical. Wettstein states that “the information conveyed by the utterance of a non-eternal sentence depends not only on the sentences uttered but also on various features of the context of utterance” (Wettstein, 1979, p. 92). In a face-to-face environment there are contextual clues that people can use to reference the indexical sentence and make meaning; this is not as easily accomplished in an online environment. Therefore, design in an online environment needs to make sequences and activities as descriptive and explicit as possible so students can understand what is meant.

According to Ally (2004) there are four main components to consider when designing online learning environments. These components are learner preparation, the learner activities, the learner interaction, and the learner transfer. For this study, only the learner activities will be studied. The data collection methods for this study limit the learner preparation or learner transfer that can be analyzed. The learner interaction will be described in constructivist design present but not in the interactions themselves. Learner activities are used with the goal of helping students achieve particular learning outcomes (Ally, 2004). For example, a learning activity could be watching a video or completing a virtual lab. When these components are put together they consist of a system of design for online learning. Moore and Kearsley (2011) note that a system is always housed within a bigger system and can have different levels of complexity. While this research focuses on the labs and design features through the potential they afford to learners, the discussion and findings should always be considered with the larger system in mind.

**Learning through media.** A question that has been debated throughout time is whether media has an effect on learning. Clark (1983) authored a foundational article in which he analyzed the influence of media on learning and found that the delivery mechanism of learning
had no significant differences on the learning outcomes. What was found in the studies was that the instructional design or strategy affected learning gains. While there are techniques unique to specific media that allow a simulation, model, or concept to be presented to students, it is not the media itself that changes the learning outcomes (Clark, 1983). It can be argued that the technology capabilities we currently have are vastly different than the technology available in 1983 and that media influences learning independent of other variables (Kozma, 1994).

When one defines technology as “a product – the tool that embodies the technology – and a process – the information base of the technology” (Peck & Dorricott, 1994) it can be reasoned that media influences learning. Different media will have different information bases and the tool used could influence learning differently. Clark (1994) responds to this argument with the ‘replaceability test’. There is going to be more than one media that can be used for learning outcomes. Designers need to make the best decision while balancing all variables (Clark, 1994). Hastings and Tracey (2004) contextualizes this argument into the ubiquitous computer era. From a systems perspective, the chosen media and the instructional design need to match to best support learning for students. For this study students in one school are completing the same virtual labs using similarly capable computers as their peers. The media remains constant and the variable is the different labs used. Student learning could in fact look very different with different labs being used. The labs are studied with the focus on the potential they offer students to learn science practices and crosscutting concepts.

**Theoretical Framework**

**Constructivism as Theory**

Many people attribute the origin of constructivism to Piaget. However, von
Glasersfeld (1995) credits the origin of constructivism to Vico in his epistemological treatise: The way of knowing, or human reasoning “can know only those things that are made of material to which it has access – which is the material of experience – and it is through the making that the knowledge of them arises” (von Glasersfeld, 1995, p. 37).

There have been many researchers who have postulated definitions of constructivism. According to Matthews (1997) the core of constructivism is a psychological position detailing how people develop beliefs. Constructivism believes that students develop knowledge by actively constructing and building on their prior knowledge (Seimars, Graves, Schroyer, & Staver, 2012). According to Herring (2004) “constructivism describes both what knowing is and how one comes to know” (p. 232). Constructivism is a commonly used learning theory to describe what happens in science (Staver, 1998) and in the science classroom (Hofstein & Lunetta, 2004; Matthews, 1997). When constructivism is used to explain what scientists do it is clear that “observations, objects, events, data, laws, and theory do not exist independently of observers. The lawful and certain nature of natural phenomena are properties of us, those who describe, not of nature, what is described” (Staver, 1998, p. 503). Nature does not attribute meaning to that phenomena, but as humans we attribute meaning to different phenomena. This belief system behind constructivism drives my analysis of the identifying aspects of constructivist learning in the design of the virtual labs.

In constructivism, knowledge is constructed both within an individual and within the community in which that individual belongs (Staver, 1998). For example, Nasir (2005) studied the playing of dominoes where knowledge was situated and constructed both within the individual and in the community in which they belong. Knowledge is built through social interactions (Stakes, 1995). In an online learning environment the social interactions are
hierarchical from learner-interface interaction, to learner-learner, learner-instructor, or learner-expert interactions, to learner-context interactions. At the highest level, the “learner-context interaction allows learners to develop personal knowledge and construct personal meaning from the information” (Ally, 2004, p. 33). The learner-context interaction gives the learner variability in the meaning they take from the information and does not limit the steps or conclusions that they can make.

A cursory overview of publically available information on cyber charter school Web sites make statements that support constructivism as an appropriate learning theory. For example, the PA Virtual Cyber Charter school has an instructional model that is “student-centered” (PA Virtual, 2015). The PA Distance Learning cyber charter school provides thorough evaluations and feedback to students in addition to using technology to reach material and information beyond the typical textbook (PA Distance Learning, 2010).

A criticism of constructivism is that learners are expected to employ effective cognitive measures resulting in adequate learning gains with minimal support (Kirschner, Sweller, & Clark, 2006). This criticism is not true to the essence of constructivism. Constructivism does not claim that students are able to actively construct and organize their knowledge in complex ways like scientists unassisted (Mayer, 2004). There are specific design features in constructivist learning environments to support students in learning. For many science concepts and phenomena, students need guidance and scaffolding to actively construct their own knowledge (Puntambekar & Hubscher, 2005). Vygotsky’s zone of proximal development (ZPD) speaks to this when he refers to the ZPD as “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable
peers” (Vygostky, 2005, p. 38). It is possible to design labs so that they assist students in reaching their ZPD. Labs are a way for “students to gain experience” (Tuysuz, 2010, p. 38). Cyber charter school labs have the potential capability to allow students to construct their own knowledge while supporting them in their zone of proximal development. This study uses constructivism as fundamental to my belief of how science is best learned that is conceptualized through constructivist design components that have been identified from the literature and emerged from the lab.

Depending on the school, students could be completing their labs individually or in a social setting. Regardless of the type of interaction all students are going to have some level of communication both with the lab itself and with their instructor. Students might have interactions with their parents or peers. Rogoff, Baker-Sennett, Lacasa, and Goldsmith (1995) emphasize that social interaction at the interpersonal level does not imply close proximity for social interaction. The messages provided to individuals at this plane can be communicated in the absence of direct contact with another person. This can be seen in Ally’s (2009) emphasis on various levels of interaction in the online learning environment from learner-interface to learner-context.

Mincemoyer (2014) showed that in one Pennsylvania cyber charter school the students do communicate with their teacher and peers in their science courses. The students could have communication with their peers as they complete the labs, but the analysis for this study are the labs themselves. An assumption of this study is that students are completing their work in relative isolation from their peers, both geographically and temporally, and this speaks to a more individual experience. The ideas from social constructivism are not used in the primary analysis of this study.
There are apparent contradictions between different theories of constructivism and using ZPD in order to respond to the criticisms of constructivism. It is important to always keep the larger system in mind when considering analysis at different levels. Nasir (2005) notes that “the specifics of the learning process and the nature of the cognitive work on the part of individual participants are rarely articulated in relation to participation in cultural activity” (p. 6). Therefore, it is not that constructivism from a radical sense (von Glaserfeld, 1995) is in conflict with more social views on learning, but, rather that researchers from respective parties do not often attempt to explain the other side (Nasir, 2005). Indeed, Staver (1998) asserts that the primary differences between radical and social constructivism is their primary focus; radical on the individual and social on the language and group. Rogoff et al. (1995) discuss the planes of communication analysis and that it is unwise to consider one plane, such as the individual, while ignoring the interpersonal or cultural planes that are interacting with that personal plane. This study looks specifically at the cyber charter school virtual science labs, which need to be conceptualized in the system in which they reside. This focuses neither on the language of the group or the individual, but rather on the object that either the group or the individual would be learning from. The learning theory of constructivism is necessary to orient the reader to how the researcher in this study believes that learning occurs. The design of constructivist learning environments is used in the analysis of the labs. Constructivist designs in a distance education environment used in conjunction with specific technologies hold the potential for turning the distance education environment from one-way knowledge transmission into an active learning environment (Jonassen, Davidson, Collins, Campbell, & Haag, 1995). For this to happen it is necessary to look at the design of constructivist learning environments.
Design of constructivist learning environments. There are many concepts associated with constructivism and designing constructivist learning environments. The foundation of any constructivist learning environment is that there is a problem, case, or project that the learners need to solve (Jonassen, 1999). All too often, schools or universities claim to focus on higher-order thinking skills and students constructing their own knowledge, only to have their curriculum emphasize rote learning (Hannafin, Hannafin, Land, & Oliver, 1997). Many of the cyber charter school Web sites highlight their curriculum by making statements such as “student-centered instructional model…to become self-motivated, lifelong learners” (PA Cyber, 2015) or to “develop critical thinking and problem solving skills” (Achievement House, 2015). Indeed, there is a divide between what does happen in technology-enhanced learning environments and what could happen in these environments (Hannafin et al., 1997). The labs in this study are analyzed with respect to the problem they present to be solved. As part of a constructivist learning environment, cognitive tools can be used to “help learners to interpret and manipulate aspects of the problem” (Jonassen, 1999, p. 218). The virtual science labs have potential to cognitively focus students on certain tasks while blocking those not considered essential to the learning outcomes for that lab. However, the labs have not been studied for their potential to be a constructivist learning environment for students.

In a constructivist learning environment “the problem drives the learning” and “students learn domain content in order to solve the problem, rather than solving the problem as an application of learning” (Jonassen, 1999, p. 218). Constructivist learning environments allow for multiple perspectives because each learner will construct their own interpretation of their experience based on many variables such as prior learning and interactions they had with the material (Black & McClintock, 1995; Vrasidas, 2000). Constructivist learning environments
should allow students the opportunity to “think like experts” (Vrasidas, 2000, p. 8). A constructivist learning environment needs to have “more construction kits and phenomenaria and place more control of the environment in the hands of the learners” (Wilson, 1996, pp. 6-7). These construction kits and phenomenaria are places where learners can manipulate and are instructionally designed to support the learner (Wilson, 1996).

A constructivist learning environment should be authentic so learners are prompted to engage in cognitive tasks that experts in the field practice (Honebein, 1996; Jonassen, 1999). For this study, the virtual labs should have students engage in science practices similar to those of scientists out in the field. However, it is important that these authentic practices are scaffolded to allow students to experience practices that scientists practice while staying within their ZPD. Constructivist learning environments need to have ‘mindful activity’. Learners need to do something and the environment needs to respond to the learner’s action (Jonassen, 1999). The virtual labs that students are using in cyber charter schools can respond to the learner’s action by, for example, showing the results of a DNA gel electrophoresis and providing feedback based on the learner’s action. It is essential that learners are given clear feedback so that they can see how their actions affected the environment (Jonassen, 1999). “Meaningful, authentic activities that help the learner to construct understandings and develop skills relevant to solving problems” are seen in constructivist learning environments (Wilson, 1996, p. 3). Learners need to be provided with support so that they are able to effectively manipulate the environment.

Constructivist learning environments need to have scaffolds to support learners. One way to support learners is to have a focus on previous cases and be able to access these cases (Jonassen, 1999). In a virtual lab this could look like learners being able to see an activity or process from a previous virtual lab that represented the phenomenon the learner was
experiencing. In a kit or observation, this could involve providing videos showing how to use certain features of the kit or what to focus on for the observation. For example, if the learner was trying to compose a figure to model the stages of mitosis, they could be provided with a similar case in which the stages of mitosis are presented. Constructivist learning environments need to provide multiple ways to look at the phenomena being studied by learners. This can increase the number of ways the learners perceive the phenomenon and develop their understanding (Black & McClintock, 1996; Honebein, 1996; Jonassen, 1999).

Learners in distance education need to have a sense of control over their learning and how effective they are at controlling their learning. There are three parts of control and these are (a) independence; (b) power; and (c) support. Independence refers to “the degree to which the learner is free to make choices within a program” (Vrasidas, 2000, p. 9). For example, in the virtual labs studied by Chen (2010) only 20% of them allow learners to design their own set-up. This means that 80% of the labs are already set-up and ready for the students to run, thus limiting their independence. Independence is analyzed in this study. More independence in the lab puts control in the hands of the student rather than the lab. There is always some level of control for the learner and at times the lab experience will seem chaotic. Having support is vital to helping learners in this chaotic environment (Wilson, 1996). “Power refers to the abilities and competencies of the learner to engage in learning experiences” (Vrasidas, 2000, p. 9). Power is not studied in this research because the learners doing the labs are not studied. “Support refers to the resources available to learners that will enable them to successfully participate in a learning environment” (Vrasidas, 2000, p. 9). These supports are distributed learning supports, scaffolds, or scripts. Supports are essential in a constructivist learning environment because they help to activate the ZPD. Power can be seen as a learner’s ZUD or zone of unassisted development,
while supports help learners in their ZPD. For example, in a constructivist learning environment for the U.S. Air Force learners receive advice as they solve the problem and reflects on their work with feedback from an expert (Gott, Lesgold, & Kane, 1996).

A specific construct from constructivism in a distance education environment used in this study is a cognitive tool, or ‘mindtool’ (Jonassen, Carr, & Yueh, 1998). According to Jonassen, Peck, & Wilson (1999) “cognitive tools are computer applications that require students to interpret and organize personal knowledge” (p. 19). An example of a cognitive tool would be a multimedia object or the backbones of a software package such as the database, system, or development behind it (Jonassen et al., 1999). In this study, the labs have the potential to be considered a cognitive tool. According to Van Joolingen et al., (2007) virtual labs can be a cognitive tool if they “boost the performance of learning processes by providing information about them” (p. 112). The processes that can improve learning are mentioned above such as reflection, metacognition, or quality problem solving. Virtual labs that provide support for these processes in the forms of scaffolds or distributed learning supports are cognitive tools. Although previous virtual labs studied have provided these supports and improved student learning (Pyatt & Sims, 2011; Zacharia, 2007) they did not take place in the context of a cyber charter school. Van Joolingen et al., (2007) note that it is necessary to consider the context when evaluating supports inherent to virtual labs.

The design components of constructivism focused on in this study are active learning environments, scaffolds, reflection, metacognition, sense-making, and problem solving. This chapter proceeds with a review of these concepts using empirical studies reflecting these environments in practice. A well-designed science lab will contain supports that reflect these
concepts. The value of the above mentioned topics have been shown in previous studies (Bransford, Brown, & Cocking, 1999; Sawyer, 2006).

**Active learning environments.** Learning environments are important in the educational experiences of students. Learning environments consist of both the learner and the context in which they learn (Wilson, 1996). The learning environment of students in cyber charter schools is filled with distractions not typically seen in traditional brick-and-mortar schools (Moore & Kearsley, 2011). Students in cyber charter schools are not affected by common distractions of brick-and-mortar schools like spontaneous social conversations or physical bullying, they face other distractions. For example, technology itself can be a distraction. Students have access to a world of information and entertainment at their fingertips. It takes a significant amount of responsibility to not use technology for reasons other than schoolwork (Olthouse, 2011). There are many variables that can affect the outcomes of student learning such as the student completing their work in their home, with or without music, with or without television, with or without assistance, and using alternative resources. The students are participating in formal learning activities in a learning environment traditionally used for informal learning.

Student-centered learning environments focus on both the student and their learning. A student-centered approach to learning realizes “that learning is nonlinear, recursive, continuous, complex, relational, and natural in humans” (McCombs & Vakili, 2005, p. 1586). Cyber charter schools are not inherently student-centered active learning environments. However, there are designs inherent to this environment that make a student-centered learning environment feasible. Virtual learning environments allow for individualized instruction with students moving at their own pace (McCombs & Vakili, 2005; Tucker, 2007). Cyber charter schools can personalize
learning paces for students and do eliminate the physical barrier between learning at school and learning outside of school because there is no physical school building (Tucker, 2007).

A cyber charter school learning environment can be described as technology-enhanced learning. A technology-enhanced learning environment is a type of active learning environment (Michael and Modell, 2003). A constructivist active learning environment is one in which knowledge is not some universal construct conceived equally by all, but rather one in which individuals construct their own meaning (Land, Hannafin, & Oliver, 2012). In a student-centered learning environment the first mentioned characteristics is preferred over the second: “rich, authentic learning contexts over isolated, decontextualized knowledge and skill, student-centered, goal-directed inquiry over externally directed instruction, and supporting personal perspectives over canonical perspectives” (Land et al., 2012, p. 5).

Constructivist learning environments are spaces in which tools, such as virtual labs, are used for students to “explore, experiment, construct, converse, and reflect on what they are doing, so that they learn from their experiences” (Jonassen et al., 1999, p. 194). There are varying levels of quality and design in online learning (Barbour & Reeves, 2009). A constructivist learning environment is not an automatic component of virtual schooling and, in particular, cyber charter-school labs. Constructivism is a learning theory focused on students’ actively constructing knowledge and thus an appropriate lens through which to view labs students complete (Jonassen, 1999). Constructivist design supports can help students engage with science practices and crosscutting concepts.

**Scaffolds and scripts.** Scaffolds and scripts are an important feature in constructivist learning environments where students are actively making sense and building their own knowledge structures (Jonassen, 1999). Without scaffolds, students may not realize their
misconceptions. In an online environment in which independent learning is expected (Barbour & Reeves 2009; Olthouse, 2011) students can easily lose track of the learning objective. An environment without scaffolding/scripts can be described as a discovery learning space in which students are not guided in their exploration and knowledge acquisition (Mayer, 2004). A scaffold is designed to help students through an activity and fade as the learner progresses in their mastery of the task (Azevedo & Hadwin, 2005). An example of a scaffold in a virtual lab would be an explanation window that could appear if a student is incorrect in their response but does not appear when a student is correct. This scaffold would fade as the student increases in their ZUD and does not need help in their ZPD to understand that part of the lab.

Many of the currently labeled ‘scaffolds’ in science education do not have the traditional features of scaffolding (Puntambekar & Hubscher, 2005). Scaffoldings needs to support a learner just beyond their current ability, fade support when it is no longer needed, channel students to focus by restricting attention to important aspects of a task, and model the task (Pea, 2004). For a part of the lab to be considered a scaffold in this study it needs to have these four features identified by Pea (2004).

A scaffold is a type of script that supports students’ engagement with a topic. A scaffold “is described as enabling interactions with students and their more able partners” (Luckin, 2008, p. 450). The primary difference between a scaffold and a script is that a script “does not require contingent support of individual students but rather requires the enactment of a teaching script…while allowing flexibility in how these activities are ordered and conducted” (Sharples et al., 2014, p. 8). All of the labs are going to have some level of script to enact that will affect how students interact with the lab. The script is going to have varying levels of descriptives versus indexicals (Wettstein, 1979). For example, the script could give more or less independence to the
learner. For this study, the scripts will be analyzed with respect to (a) the types of interactions they afford the learner; and (b) the amount of independence and support they provide to the learner. Tsovaltzi et al. (2010) created a collaborative script for virtual chemistry labs to help prompt “social processes beneficial for learning” (p. 95). The scripts and scaffolds in their study were based on the practices that experts engage in when doing science.

Individual features of the virtual labs could be considered a contingent scaffold. For example, the virtual lab could have a scaffold that models how to complete a process such as running a centrifuge. This could appear for all students the first time that they complete the activity but then the modeling would fade as students are able to explain how and why a centrifuge works. Mindtools help to “scaffold different forms of reasoning” (Jonassen et al., 1998, p. 24). A virtual lab could have a window appear to help students metacognate that would allow for “cognitive reflection and amplification” (Jonassen et al., 1999, p. 153) Metacognition, reflection, and sense-making are all potential scaffolds that might be embedded in the design of a lab. If a support is seen in the lab that fosters one of these cognitive processes but does not have the essential features of a scaffold identified by Pea (2004) it will be marked as a ‘distributed learning support’.

**Metacognition.** Metacognition is concerned with knowing about one’s own cognitive processes (Flavell, 1979). Metacognition is inextricably linked to one’s epistemological beliefs about learning (Bromme, Pieschl, & Stahl, 2010). The components of metacognitive knowledge are “person, task, and strategy” (Flavell, 1979, p. 907). At the personal level metacognition relates to what a person epistemologically believes about their own learning and the cognition of others. At the task level, metacognition refers to how much information is available for a certain task and knowing how best to deal with the information presented (Flavell, 1979). Finally, at the
strategy level, metacognition is concerned with what strategies are going to allow a student to become aware of their own cognition and the best way to learn specific material and concepts (Flavell, 1979). There is more than one way to design scaffolds for students in their metacognition or to think that all metacognitive scaffolds are ‘good’ (Thomas, 2012).

In a similar manner to how learning cannot be removed from the context in which it is learned (Greeno, 1998), metacognition, a component of learning, cannot be considered apart from the environment in which students are placed. There is a lack of agreement on how best to study and evaluate metacognition with both positivist and interpretivist lenses being used (Thomas, 2012). However, there is no debate on the importance of metacognitive scaffolds in a computer-based learning environment to support student learning (Azevedo & Hadwin, 2005).

Metacognitive skills is the other major type of metacognition. Whereas metacognitive knowledge is what a person presently knows about how to learn in a specific situation, the metacognitive skills are the processes that take place when a learner is trying to learn about their own cognition (Bannert, 2006). The components of scaffolding that are used in metacognitive prompts are “diagnosis, calibrated support, fading, and individualization” (Azevedo & Hadwin, 2005, p. 370). Students focusing on metacognitive skills through scaffolded prompts can help to improve students’ metacognitive knowledge.

Metacognitive prompts and activities in a computer-based learning environment can serve as a scaffold for students’ metacognition and self-regulation of their learning (Azevedo & Hadwin, 2005). When students are engaging with science metacognitive prompts provide the modeling needed for students to conceive of science in terms of the nature of science, science practices, the intersection of science and society, and crosscutting concepts (NGSS, 2013; Peters & Kitsantas, 2010).
Research emphasizing the failure of computer-based learning attribute much of the failure to the lack of self-regulation in students (Azevedo & Hadwin, 2005). A previous study on nature of science metacognitive prompts used mixed-methods to measure the metacognitive gains of students in an experimental and comparison group. The results showed that the quantitative results were statistically significant between the two groups in terms of their nature of science explanations and content knowledge but not in their metacognition. The qualitative results gave deeper insights into the students’ metacognitive knowledge. Students who were in the control group were unable to explain how they knew something and did not think “about the nature of science” (Peters & Kitsantas, 2010, p. 391). The experimental group of middle school students responded to qualitative questions regarding what it means to think scientifically in ways that reflected the nature of science. Whereas, the comparison group answered the questions in ways that were reflective of the scientific method rather than the nature of science (Peter & Kitsantas, 2010). In addition, students in the experimental group were able to better reflect on how they knew they learned specific material (Peter & Kitsantas, 2010). The metacognitive findings came from the qualitative aspect of the study. It is recognized that the way these researchers have defined the nature of science are not in agreement across the science education community. However, this study does not need to explain these differences as nature of science metacognitive prompts are not specifically identified. Metacognitive prompts in a virtual lab focused on the nature of science should emphasize expert ways of thinking.

An alternative way for metacognition to be used in science inquiry instruction is to help students process which variables to control. Klahr and Dunbar (1998) view a distinction between students who theorize by generating hypotheses and then testing them versus students who experiment and collect data and then try to explain their data. The experiment learner is not
efficient in their study of a phenomenon. Chen and Klahr (1999) found that without scaffolding and direct instruction, students are likely to design a study with confounding variables. However, with training and probing questions, students, even at the elementary level, were able to design unconfounded experiments.

**Reflection.** Reflection is a key scaffold to help students learn how to self-regulate and think about what they learned. The ability to reflect on what was learned has been shown to increase likelihood of transfer to a new task (Bransford et al., 1999). When designing a learning activity, there are design decisions associated with reflection that need to be considered. One of the design decisions involves the prompts used for reflection and the activity that students will complete when responding to the prompts (Ash & Clayton, 2009). Regardless of the wide structure that reflective activities take, they are an important component of an active learning environment because they help students to “articulate their developing understandings” (Sawyer, 2006, p. 12) and reflect on those understandings. It is important for the scripts in the virtual labs to incorporate scaffolds related to metacognition and reflection. Students engage in natural reflection when it is around a topic that they know and are familiar with, but “it is difficult to engage in self-regulation and reflection in areas that one does not understand” (Bransford et al., 1999). Reflection helps students think about what they have learned and integrate it into their knowledge acquisition process (Davis, 2003). Previous research shows the misconceptions that students have about heredity, a core idea of the life sciences (Browning & Lehman, 1988; Cho, Kahle, & Nordland, 1985; Shaw, Van Horne, Zhang, & Boughman, 2008). Reflective prompts can be useful in areas that students do not understand deeply as can be seen through their misconceptions.
Reflection prompts are shown to increase transfer when compared to environments where students are not prompted to reflect (Bannert, 2006). There is conflicting research on whether reflection prompts in an active learning environment should be generic or directed. Davis (2003) found that generic prompts were more effective for productive knowledge integration and directed prompts led students to certain responses. Other reflection prompts in computer-based learning have asked students to make hypotheses and then reflect on the data collected in relation to their hypotheses (Edelson & Reiser, 2006). Krajcik and Blumenfeld (2006) emphasized that the implicit aspects of a scientific practice need to be made explicit for novice students to consider the practices in their reflection about a topic. Reflective prompts that make implicit aspects explicit are more direct than generic prompts. Generic prompts ask questions such as “right now, we’re thinking” (Davis, 2003 p. 92). However, these prompts do not guide students into thinking explicitly about a topic.

Reflection prompts can be offered with or without feedback for students. In an experimental study it was found that including feedback with reflection increased scores for regulating learning. Using reflection without feedback did not note any statistically significant results (van den Boom, Paas, van Merrienboer, & van Gog, 2004). Regardless of the exact structure of a reflective scaffold in a virtual lab, it is important to include opportunities for students to reflect on both metacognitive and sense-making processes.

**Sense-Making.** Sense-making is related to reflection and metacognition. When students are proficient in sense-making, they are expected to realize when a concept does not make sense and ask for further clarification (Bransford et al., 1999) If students do not engage in reflection and metacognition, either implicitly or explicitly, then their sense-making processes would fail because they would not recognize what does not make sense. Sense-making is an integral part of
scientific inquiry/practices. Sense-making refers to activities “such as generating hypotheses, designing comparisons, collecting observations, analyzing data, and constructing interpretations” (Quintana et al., 2004, p. 344). Sense-making begins when students create a hypothesis and continues into the data interpretation and communication of results. When students engage in sense-making processes they must use formal representations to represent information and knowledge gained (Quintana et al., 2004). When students are completing science labs (physical or virtual) they need to be able to realize what part of the lab or experiment they are working on, how it relates to other parts, and if they are arriving at acceptable solutions (Sandoval & Reiser, 2004).

Sandoval and Reiser (2004) designed the ExplanationConstructor to prompt students and scaffold their thinking in epistemological and conceptually efficient ways. This study showed that a scaffold can guide students towards productive sense-making, but there were weaknesses in how students engaged in reflection and the reflections did not extend much beyond the computer reflections (Sandoval & Reiser, 2004). These results prompted the next iteration of ExplanationConstructor in which students were more explicitly guided to use data when substantiating their claims (Sandoval & Reiser, 2004). Sense-making prompts included in virtual labs should explicitly scaffold students to provide reasons for their claims and arguments. Sense-making is part of both quality metacognition and reflection because it helps students to focus on what they need to know the processes to help them learn what they need to know.

Problem solving. Problem solving is a skill needed by all scientists. There are differences in the way that novices and experts solve problems (Bransford et al., 1999). Scaffolding and scripting students’ problem solving through can help them to approach problems in a similar manner to experts. This scaffolding design can be a computer scaffold or teaching strategy
Problem solving can be well-structured or ill-structured. “Well-structured problems are constrained problems with convergent solutions” whereas “ill-structured problems possess multiple solutions, solution paths,… and contain uncertainty about which concepts, rules and principles are necessary for the solution or how they are organized and which solution is best” (Jonassen, 1997, p. 65). There are different processes and strategies used when students engage with well or ill-structured problems. The vast majority of problems encountered in schools are designed to be well-structured even though most of the problems encountered in work scenarios are ill-structured (Shin, Jonassen, & McGee, 2001). For students to articulate how they will solve a problem, cognitive tools can be used. The labs explored in this study serve as a potential cognitive tool to amplify and externalize “students’ internal representations” of the problems they encounter (Jonassen, 2003, p. 362). Ill-structured problems are ideal to prepare students “to meet the demands of the knowledge-based economy” (Chin & Chia, 2005, p. 45). For the purpose of this study, the type of problem encountered will be classified as to whether it is well or ill-structured and if the lab is used to internalize how students approach problem-solving.

**Conceptual Framework**

**Scientific Concepts and Practices**

*Scientific practices.* The type of science instruction that students typically experience in school presents science as facts where students are not expected to construct their own explanations of science (Sandoval & Reiser, 2004). Teaching science using inquiry, in contrast, involves students building and revising theories (Sandoval & Reiser, 2004). Using inquiry in science to help students learn has been recommended since the time of Dewey (Barrow, 2006). Recently, the term science practices has been the preferred vernacular over scientific inquiry to
reduce multiple understandings of what inquiry is. The notion of students taking active roles in their learning and asking questions in science is currently and historically an essential component of inquiry (Barrow, 2006). Edelson, Gordin, and Pea (1999) state that inquiry is important in science because “science is essentially a question-driven, open-ended process and that students must have personal experience with scientific inquiry” (p. 392).

The NGSS emphasize the term ‘practices’ over inquiry not to downplay the role of inquiry in science. Rather the term ‘practices’ is intended to emphasize “the diversity of what scientists actually do” (Pellegrino et al., 2014, p. 29). Inquiry has been used in many different settings, and using the term practices is intended to give a specific understanding of what is meant by inquiry in the NGSS (Quinn et al., 2012). Therefore, although previous studies have focused on scientific inquiry this study will use the term science practices to stay in alignment with the NGSS.

According to the NGSS there has been a focus on how science, technology, and society intersect. There have been significant changes when new technologies are developed and people respond to and act with new knowledge in technology and science. This is exemplified from the NRC as cited in the NGSS

Not only do science and engineering affect society; society’s decisions (whether through market forces or political processes) influence the work of scientists and engineers. These decisions sometimes establish goals and priorities for improving or replacing technologies; at other times they set limits, such as in regulating the extraction of raw materials or in setting allowable levels of pollution from mining, farming, and industry (p. 212).

When students are prepared with science practices that teach them not only concepts in science, but how systems interact with one another and a more general sense of ‘holistic inquiry’ (Chen, 2010), they will be better prepared to understand significant decisions and issues around science and society. The integration of science practices, crosscutting concepts, and core ideas as
recommended in the NGSS is a challenging one. However, using a constructivist learning environment allows for students to learn content by engaging with science practices crosscutting concepts. Core ideas were originally going to be analyzed in this study. However, content knowledge has been studied in several other studies with virtual labs (Pyatt & Sims, 2011; Zacharia & Olympiou, 2011) and decisions need to be made to focus the study. The cyber charter schools in this study did not all teach the same content in middle school science. Originally, the core ideas were going to be from life science, but while some schools taught life science there was frequently a mixture of subjects covered and the focus on specific core ideas with which the researcher had expertise was not feasible. Science practices and crosscutting concepts have not been identified in any virtual lab study and this represents new knowledge added to the field.

There are challenges in engaging students with science practices. Edelson et al., (1999) used technology-supported inquiry learning and responded to challenges encountered when using this learning with students. The issues Edelson et al., (1999) encountered in using inquiry in technology learning environments were: (a) motivation for learners; (b) knowledge of the scientific techniques to use; (c) having inadequate content knowledge to use with science practices; (d) inability to self-regulate tasks and behaviors; and (e) lacking the proper learning environment to conduct inquiry tasks. Computers can support inquiry when they are used as tools to aid learners (Edelson et al., 1999). Computers can provide an authentic and motivating environment for students (Zumbach, Schmitt, Reimann, & Starkloff, 2006). It is not enough to place computers in front of students and expect them to know how to learn from them. Students develop scientific literacy when they engage with science practices (Zumbach et al., 2006). It is not easy to engage in science practices without assistance. Two of the issues identified in Edelson et al., (1999) were the learner’s inability to know how to properly collect and apply data,
and to understand how different parts of science practices apply to science practices as a whole. A constructivist learning environment that situates knowledge in a context can help students to relate the parts to the whole (Vrasidas, 2000).

**Nature of science.** Having students understand the nature of science has been a goal of science educators for years. There is significant debate between scientists as to what is meant by the nature of science. Some researchers conceive of the nature of science as one-dimensional, while others focus on the multidimensionality of it. Still others believe that the nature of science is related to how students are able to apply scientific inquiry when completing a task (Harrison, Seraphin, Philippoff, Vallin, & Brandon, 2015). The NGSS reflect on the nature of science as a way to integrate the fusion of core ideas, science practices, and crosscutting concepts into the curriculum for students. It is important for the general public to understand the world in which they live. Crucial to this understanding is understanding the nature of science. The nature of science reflects on the fact that all science knowledge can be modified or revised based on new knowledge (NGSS, Appendix H, 2013). Students should learn the nature of science by applying it through core ideas, science practices, and crosscutting concepts.

Harrison et al., (2015) used an expert team to determine how the nature of science described in the NGSS aligned with empirical studies about the nature of science. They created five models for how to best treat the nature of science. The resulting analysis showed that model four “which treated NOS as multidimensional according to the NGSS NOS themes” was the best fit (Harrison et al., 2015, p. 11). This model integrated the nature of science themes that the NGSS separated as either a science practice or crosscutting concept into one model with the core ideas separated. This suggests that a separation of science practices and crosscutting concepts is not needed when studying the nature of science. However, this study does not look at students’
understandings of the nature of science. It is useful to separate science practices and crosscutting concepts in this study to create a heuristic for analysis of the science practices and crosscutting concepts.

**Science Practices in the NGSS**

The science practices that students engage in during the course of their study should reflect the authentic activities of scientists. Labs should be designed to allow students to engage in the following activities that scientists do: “asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information” (Quinn et al., 2012, p. 3). A virtual lab has the potential to expose students to many of the above practices and concepts. It is unlikely that one lab will incorporate all of the science practices and crosscutting concepts. As a cumulative whole, a sequence of virtual labs has the potential to engage students with many science practices and crosscutting concepts. If a lab is particularly lacking in the practices and crosscutting concepts, then it becomes more likely for the student to miss the ‘whole’ of scientific investigation (NGSS Appendix H, 2013). Incorporating strands science practices and crosscutting concepts allow for a fusion of understanding for the students. This fusion of ideas is fundamental to exposing students to the nature of science. Without experiencing science as fusion, students might not have the experiences necessary to develop the scientific literacy necessary to positively contribute to conversations about science and technology (Appendix J, 2013).

**Scientific practices.** The virtual labs were analyzed with respect to the potential the labs have to engage students in science practices. Being able to ask questions is a prerequisite of
being scientifically literate. Students should ask questions so that they can “formulate and refine questions that can be answered empirically” (Quinn et al., 2012, p. 55). Asking questions should be used for finding evidence to support claims or to explore patterns (Quinn et al., 2012). Any part of the virtual lab that has students generate questions or provides prompts for students to think of questions will be categorized in science practices as asking questions.

The second science practice is using models. When students use computer simulations there is an assumption that learners need to be able to effectively evaluate the model to see what is represented (De Jong & Van Joolingen, 1998). For example, a virtual lab could model the process of mitosis. Students would need to understand the process of mitosis from the model. Models can selectively focus on certain aspects of a phenomena. A well-structured conceptual model might support students in forming more appropriate mental models of a phenomena (Quinn et al., 2012). The virtual labs will be analyzed for models for students to use or develop.

The third science practice, designing and enacting investigations, is critical to laboratory investigations. Designing a good science investigation, much like forming a research question when writing a dissertation, is a difficult task. Students need practice designing experiments that can provide the right data to be able to answer the research question (Quinn et al., 2012). This is a very complex process and an excellent virtual lab that provided opportunities for students to design an experiment and carry out those investigations would have this practice marked in the lab. Chen (2010) observed that 1% of the 220 physics labs he studied included an opportunity for students to engage in reflection or acknowledge measurement error. Errors are a natural part of the scientific process and processes like making errors, choosing variables, and sample selection should be included when students are designing experiments (Quinn et al., 2012). This is summarized well in the NRC Framework:
students need opportunities to design investigations so that they can learn the importance of such decisions as what to measure, what to keep constant, and how to select or construct data collection instrument that are appropriate to the needs of an inquiry (Quinn et al., 2012, p. 60).

The virtual labs are evaluated for their potential to engage students in decisions that need to be made during the course of a laboratory investigation for data-collection.

Regardless of the design of the lab, a reasonable next step is to analyze the collected data. The ability to organize data is necessary when conducting analysis. Organized data allows for the students to be able to answer possible research questions and see patterns in the data (Quinn et al., 2012). Students need to be able to organize data in a way that allows them to see if their hypothesis is correct or incorrect (Quinn et al., 2012). In middle school “students should have opportunities to learn standard techniques for displaying, analyzing and interpreting data” (Quinn et al., 2012, p. 63).

The fifth science practice is using mathematical thinking. Mathematical thinking helps scientists to communicate and understand the probability and inferences in the world around them (Quinn et al., 2012). Computational thinking is used when designing simulations and representing the data visually (Quinn et al., 2012). Students need to be able to use mathematical thinking to use and understand units of science (Quinn et al., 2012). The virtual lab should have the potential to engage students in mathematical thinking.

Scientists need to be able to coherently explain their findings and evidence supporting the findings. Students need to be given the opportunity to investigate established scientific theories/explanations as well as develop their own explanations around a phenomenon (Quinn et al., 2012). There is frequently more than one theory or hypothesis to explain a phenomenon and it is important for students to see how scientists use data to support their claims (Quinn et al.,
Students need to be able to explain what is occurring within a phenomenon, and recognize when they do not fully understand or adequately explain a concept (Quinn et al., 2012).

To successfully justify explanations or findings, students will need to use arguments from evidence. In the scientific world this is an iterative process. Scientists use evidence to support their claims while other scientists counter their claims and expose weaknesses in their explanation (Quinn et al., 2012). When engaging in argumentation students should be able to construct an argument, explain weaknesses in their argument, and respond to criticisms. Students should be able to do this both for their own work and for understanding the historical development of scientific theories and explanations (Quinn et al., 2012). A virtual lab that has the potential for students to engage in argumentation would, for example, present a different explanation and require students to use data to justify their claims.

The eighth science practice is to gather and communicate information. Scientists are expected to infer information from multiple sources such as text, graphs, and models. Students need to clearly communicate what they learned from scientific texts and models (Quinn et al., 2012). The virtual labs should be structured as to give students the opportunity to communicate so their thoughts are made explicit (Krajcik & Blumenfeld, 2006), and to share their findings with the broader community.

**Crosscutting concepts.** There are seven crosscutting concepts that unify science disciplines. These concepts are “patterns, cause and effect, scale, proportion, and quantity, systems and system models, energy and matter, structure and function, and stability and change” (Quinn et al., 2012, p. 84). The virtual labs will be evaluated with regard to how visible they make crosscutting concepts available to students. A critique of science education is that students are expected to acquire a deep level of understanding about the nature of science without being
explicitly supported (Quinn et al., 2012). Making the crosscutting concepts explicit can improve students’ understanding of science.

The first crosscutting concept is patterns. Patterns are ubiquitous and students who are able to discern patterns can ask more appropriate questions about science (Quinn et al., 2012). Patterns help to classify different things according to similar features. An example of identifying patterns in the life science would be genotypes and phenotypes. A lab could incorporate a feature like the ‘report’ function in the life sciences lab to make the patterns explicit to students (Zumbach et al., 2006).

The second crosscutting concept is cause and effect. It can be difficult to discern what causes an action to happen. Cause and effect is frequently related to mathematical thinking because it involves probabilities. Cause and effect is a systemic concept. For example, one may look at a newborn baby and see that it is a human. However, the actions that caused certain features to develop is a more complex relationship to make. Cause and effect can be used in science to help students consider what caused a certain even to happen (Quinn et al., 2012). A lab could be designed to prompt students to reflect on what caused, for example, moths to change color in response to their environment.

The third crosscutting concept has to do with measurements and how concepts can change in response to the scale used. Virtual labs are able to alter scale and allow students to explore phenomena that would not be possible without technology. For example, studying very large or very small processes is not feasible in a typical science classroom. Virtual labs can have simulations that represent these phenomena for students. Students should be able to know when it is appropriate to use certain scales or measurement units (Quinn et al., 2012). A virtual lab could take advantage of ill-structured problem solving when using scales (Jonassen, 1999). The
virtual lab could prompt students to choose the appropriate scale to apply or explain their rationale for choosing that scale.

The fourth crosscutting concept is systems. A system is defined as “an organized group of related objects or components that form a whole” (Quinn et al., 2012). It is too complex to study an extremely large system at once. Therefore, it is important to be able to select the appropriate level of the system to study. For example, if students are studying the effects of fertilizer run-off on the Chesapeake Bay it is important to know what level to study the system. A lab could do this by having students select the appropriate scope to study the Chesapeake Bay according to the research questions. For example, a question concerning the impact of bay health on the animals who live near the Chesapeake could be investigated as well as how this run-off impacts the larger water system. To investigate the first question, an appropriate scale would be at the population of an animal whereas the second question could have the scale of surrounding waterways and their pollution levels.

The fifth crosscutting concept is energy and matter. Primarily this is concerned with the transfer of energy between systems. At the middle school level concepts around energy and matter are discussed (Quinn et al., 2012). Labs intended for the middle school level should therefore focus on energy and flow such as the water cycle or kinetic/potential energy.

The sixth crosscutting concept is structure and function. A student needs to understand the structure and function of a living thing to understand why that living thing behaves the way it does. (Quinn et al., 2012). A lab can have designed scaffolds and supports to direct students to the structure and function of a living thing. For example, the function of immune systems is to keep us healthy. A lab on viruses could show the structure of immune cells such as white blood cells and how the structure of the virus impacts the function of the immune cells.
The final crosscutting concept is stability and change. Things are rarely in a state of inertia. Even something that looks relatively static at a certain scale is not actually inert. It is important for science instruction to show to students that even still systems are in some sort of equilibrium. Students also need to see the parts of the system, such as the mechanisms, that are unchanged so that the system can persist (Quinn et al., 2012). At the middle school level students should be able to understand multiple variables that are affecting the rate of change of a system (Quinn et al., 2012). A lab could be designed to look at metamorphosis and what prompts the development and change of an organisms with prompts to make this process more explicit for students.

**Science Laboratory Investigations**

Science laboratory investigations have a long history of use in science classrooms. According to Balamuralithara and Woods (2007) the science lab affords students the opportunity to gain “practical knowledge and experiences” (p. 108). At one point in time there was not a question as to whether science labs should be included in science courses. The history of using science labs in a science course dates back to the 19th century. During the 1960s laboratory investigations became a focal point of science class to help students experience the process of science (Hofstein & Lunetta, 1982). Science laboratory investigations give students the ability to interact with processes and activities that can build competency in science inquiry. Science labs that are built around scientific inquiry and inquiry processes are fundamentally different than labs that are used to “illustrate, demonstrate, or verify known concepts and laws” (Fuhrman, Lunetta, Novick & Tamir, 1978, p. 12). Chen (2010) classifies the first description as holistic inquiry and the second as hypothetico-deductive. Successful labs have guidance and worksheets for students to structure their experience. The guidance should allow “students to distinguish
among their own ideas and the ones demonstrated by the investigation” (de Jong, Linn, & Zacharia, 2013, p. 306). It has been shown that virtual labs produce similar conceptual change to physical labs (de Jong et al., 2013).

There are limitations to both physical and virtual labs. Physical labs can promote students thinking about imperfect measurements and produce a more complete understanding of a science phenomenon. Virtual labs can allow for a clear relationship between variables, and allow for experiments to be conducted that could not be done in a physical lab. The ideal way to experience labs is to use both physical and virtual labs together (de Jong et al., 2013). A previous investigation of virtual labs by Chen (2010) shows that many of the virtual labs on the market embody the ‘show-and-tell’ design. Fuhrman et al., (2012) emphasize this is the design of labs that are made for verifying existing knowledge. This design limits the amount of ill-structured problem solving and unclear outcomes that students think through as the solution is already known. Questions on the worth of students completing science labs had to do with the goals for laboratory investigations. The defined goals for laboratory instruction were not significantly different than the defined goals for science instruction in general (Hofstein & Lunetta, 2004).

Since that time significant progress has been made in understanding how people learn including the foundational How People Learn by Bransford et al. (1999). Within How People Learn the differences between how novices and experts acquire, organize, and store knowledge were fleshed out. The NRC Framework for science education used the notion of novices and experts to help structure the way that students experience science in schools (Quinn et al., 2012). One of the strategies to enable students to think more like experts was to have students “learn the core ideas through engaging in scientific … practices” (p. 25). The scientific practices established resemble what an ideal science laboratory investigation could look like in a student-
centered classroom. The scientific practices identified in the framework are “asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information” (Quinn et al., 2012, p. 3). The NGSS established in 2013 based on the NRC Framework are the latest recommendations in helping students gain experience in science practices. An important outcome of the NGSS is that some of what was previously thought of as scientific inquiry is now considered a science practice. The science practices identified above still connote a similar sense of inquiry, but now they are expected to be tied to the knowledge from a core idea for students to apply that knowledge in practice (NGSS Appendix F, 2013). In addition, these science practices resemble what scientists do in the field and are well-defined. The science laboratory serves as an environment for students to gain skills with science practices.

The science laboratory is a place where students can work collaboratively and in groups to develop understanding and explore phenomena (Hofstein & Lunetta, 2004). Science is a fundamentally social and collaborative process. Even when scientists work individually, they are tapping into a collective knowledge base (Quinn et al., 2012). The actual communication of students will not be revealed in this study, but the markers in the lab that have the potential to support students in their communication will be identified.

Sawyer (2006) asserts that the reason that the full potential of using computers in schools has not been reached is because the software is not designed to foster deep learning. Learning in collaborative settings does not diminish in importance when the setting is virtual (Rummel & Spada, 2005). In this study, interviews with teachers are completed to understand the
communication students engage in when completing their labs. Analyzing the virtual labs for embedded design features to support communication are important to understand what is and is not currently being done in the design of virtual labs that cyber charter-school students are using to support communication.

Virtual science labs. The history of using computer simulations for science laboratory investigations originated in the 1970s (Magin & Reizes, 1990). Since that time the technology capable of designing, developing, and delivering virtual simulations and labs has improved. There is a slight difference in the definitions of simulated and virtual experiments. In a virtual experiment students are expected to prep the virtual equipment whereas in a simulated experiment there is no need for students to prep the equipment (Crippen, Acrhamabault, & Kern, 2013). In addition, students can be passive observes in a simulation but need to manipulate materials in a virtual lab (Scalise, Timms, Moorjani, Clark, Holtermann, & Irvin, 2011). Through the course of this study, the virtual labs evaluated will be classified according to whether they are experiments, or simulations, and whether they involve manipulation, or observation. There are numerous studies exploring virtual labs, the characteristics of virtual labs, and comparisons of learning gains and student experiences in physical and virtual labs. The vast majority of these studies have ignored the context, teacher support, and design of the virtual labs (Rutten, van Joolingen, & van der Veen, 2012). In addition, many of the previous studies on virtual labs have been criticized of attributing too much of the student learning to the technology without isolating the variables (Scalise et al., 2011). Virtual labs have the potential to engage students in activities such as “exploring the nature of science, developing team work abilities, cultivating interest in science, prompting conceptual understanding, and developing inquiry skills” (de Jong, Linn, & Zacharia, 2013, p. 305).
However, just because virtual labs have the ability to provide this learning environment for students does not mean that all virtual labs engage students in those activities. This is the foundation of this study, is there potential to engage students in the science practices and crosscutting concepts considered so fundamental to the learning of science in the company of peers and instructors. This goes beyond the traditional definitions of labs to what teachers are using in cyber charter schools. For example, through a conversation with a teacher it was found that the teacher used virtual labs but found them too challenging for students to do on their own. The teacher then took YouTube videos and edited them so the students could observe and ask questions when someone else completes the lab.

One of the significant differences in cyber charter-schools versus brick-and-mortar schools is that the teachers are less likely to be the designers of the course or curriculum (Moore & Kearsley, 2011). In this study, the virtual labs were designed by the teachers in 3 of the 5 schools, using software that the teacher customizes to deliver the virtual lab to students. However, those teachers have more autonomy in what and how they use materials than in the schools with a purchased curriculum. Administrators and teachers are faced with how to best deliver science lab experiences to students in cyber charter schools. Choosing certain virtual science labs can be a more cost-effective option than sending physical manipulatives to students (Crippen et al., 2013). Achievement House Cyber Charter School is “the first cyber school in the country to offer the Project Lead the Way curriculum” for math and engineering at the high school level (Achievement House, n. d., para. 1). However, this school uses virtual labs for their middle school science curriculum.

Certain science phenomena may be best presented through a virtual lab. Virtual labs provide unique advantages over physical labs in that the time for an experiment to be completed
is reduced, previously unobservable phenomena can be virtually represented for students, and certain items associated with physical labs can be discarded to focus attention on the important scientific concepts and practices conveyed by the lab (de Jong et al., 2013). From the student perspective, virtual labs are not preferred to physical labs because they are not perceived as interactive or hands-on (Raish, Tang, & Carr-Chellman, 2012). This point differs from an assertion by Klahr et al., (2007) that the virtual labs can still be considered hands-on because students are in control of the computer. The students do not perceive it this way. Virtual labs are preferred by students for being able to reference them as learning supports after the lab is complete (Raish et al., 2012). For example, students studying chemistry cannot conduct certain physical investigations because of the inherent danger in the interaction between chemicals. In such a case, virtual labs are an important option in either traditional or cyber settings. In addition, well-designed computer simulations can help focus students on acquiring specific skills or strategies. Variables can be controlled in a virtual simulation. Bransford et al., (1999) report on a study where students acquired problem-solving skills more similar to experts through a scaffolded computer simulation than students who did not have the scaffolded simulation.

De Jong et al., (2013) conducted an extensive empirical literature review of studies comparing physical and virtual labs and found that there have been no significant differences in the conceptual knowledge of students who completed either type of lab reported in three studies on virtual labs. However, as Chen (2010) points out, there needs to be an evaluation of virtual labs in the broader context of the goals of science education, instead of analyzing them solely for their ability to teach conceptual knowledge. Learning the content knowledge does not mean that students are also learning science practices and crosscutting concepts (Quinn et al., 2012). The
NGSS belief that students learn core ideas through engaging in science practices and crosscutting concepts is not analyzed if the focus is only on conceptual knowledge.

Virtual labs should be evaluated in accordance with the skills and practices that students are expected to gain through laboratory experiments (Chen, 2010). Of the 233 virtual labs that Chen (2010) evaluated through content analysis, 80% of the labs are ‘ideal cases’ in which multiple variables are not allowed to be manipulated and “for 99% of the VLs, students need not be concerned with error sources nor reflect on experimental design” (Chen, 2010, p. 1126). In these virtual labs, ill-structured problems are not seen in 80% of the cases and students are not expected to reflect on the design of the experiment in 99% of the cases. While virtual labs have been found to be effective in teaching conceptual knowledge about science, they tend to ignore the messiness of authentic scientific inquiry and multiple variables affecting the possible results of the lab (Chen, 2010). For students in cyber charter school, the ability of virtual labs to provide students with an environment to engage in the ‘messiness’ of science becomes even more important as these students lack classroom opportunities for investigations. The ideal model may be to combine physical and virtual labs to experience the advantages of both (de Jong et al., 2013). Unfortunately, for the vast majority of students in cyber charter schools combining physical and virtual labs is not a feasible option. Schools tend to make the choice to use either at-home kits, virtual labs, or webcam labs completed by the teachers for specific labs without using more than one lab for each module/lesson. A school could use a virtual lab for one lab but at-home materials for another lab. Therefore, it is critical that all of the labs the students use are designed with science practices and crosscutting concepts in mind, and with adequate supports for students.
Previous researchers and studies have explored various dimensions of virtual science labs. Pyatt and Sims (2011) explored the impact of virtual labs on student learning and attitudes and found that while students preferred the virtual medium to physical labs, the common factor in enjoying the labs was having them inquiry-focused. This study found that students experienced equal to greater conceptual change in virtual and physical labs in a chemistry class. However, limitations of this study are that the assessment did not measure students’ ability to do many of the tasks related to scientific practices such as “effectively design an experiment…effectively gather and collect data…ability to analyze and interpret their results…and apply and integrate their interpretations and findings to explain the overarching phenomena or conceptual model under investigation” (Pyatt & Sims, 2011, p. 143).

In interactive physics simulations with undergraduate students it was found that virtual simulations that use cognitive perturbation are more effective than virtual simulations that use cognitive conflict (Dega, Kriek, & Mogese, 2013). Cognitive perturbations are different than cognitive conflict strategies because they “provide appropriate dissonance to gear students’ conceptual change towards a more scientifically inclined one” whereas cognitive conflict strategies put “confrontation and denial of alternative conceptions in the first place” (Li, Law, & Lui, 2006, p. 407). The limitation of this study relevant to the current research is that it focuses solely on strategies for conceptual change whereas the current study will develop a framework to identify if science practices and crosscutting concepts are present for students supported by constructivist design features.

Crippen et al., (2013) conducted survey research in which data was collected from teachers who taught in virtual schools about “how and why laboratory activities are enacted” (p. 1036). The purpose of including this study in the literature review is to provide the teacher
perspective on virtual labs and their components. These laboratory experiments are represented through a mixture of hands-on, simulated, and virtual experiences. A fundamental component of science education, the nature of science, is largely missing from these virtual labs. For example, while many of the labs were student-centered and required students to collect data, they did not often cultivate practical skills (only 22%), encourage discourse (6%), foster collaboration (2%), looking at the error in labs (1%), or “understanding the complexity and ambiguity of empirical work” (0%) (Crippen et al., 2013). The survey used for this study underwent expert review and a pilot to make sure that the intended questions and comments were interpreted clearly. (Crippen et al., 2013). Stuckey-Mitchell and Stuckey-Danner (2007) call for the need for more research around virtual science labs, especially in the field of biology. Stuckey-Mitchell and Stuckey-Danner (2007) used an online survey to determine whether students preferred virtual or physical labs. From the student perspective at the undergraduate level, students preferred face-to-face labs to virtual labs in regards to all questions. For example, it was found that 69.5% of students agreed or strongly agreed with the idea that the face-to-face lab prepared them for evaluating science information heard in the news where only 34.8% of students agreed or strongly agreed that the virtual lab prepared them to do this. When considering that one of the goals of the NRC Framework is to equip students to participate in public conversations about science or engineering concepts this is concerning. Students found that the virtual labs were lacking feedback, interactivity, and community building. A well-designed virtual lab could have all of these features. Even at the conceptual level, which other researchers have shown through experimental designs that virtual labs produce equivalent or greater conceptual change (Klahr et al., 2007; Pyatt & Sims, 2011; Zacharia, Olympiou, & Papaevridou, 2008) students found virtual labs to be less effective than face-to-face labs (86.9% viewed face-to-face labs as helping to
understand course content where only 60.8% of students viewing virtual labs as effective in helping to understand course content).

In another study, a comprehensive team was established to design a life science lab for students to use. The overarching design consideration when creating this virtual lab was to allow “a high degree of self-directed learning in combination with instruction elements like coaching and scaffolding” (Zumbach et al., 2006, p. 285). The team designed four levels of expertise that the labs can help students achieve. The first level was for students to “be able to activate prior knowledge, understand basic concepts of new domain” and the design strategies to achieve this were to use “analogies, authentic scenarios, challenging missions” (Zumbach et al., 2006, p. 286). The second level was for students to “be able to acquire domain specific declarative/procedural knowledge” and the design strategies to achieve this were to use “guided experiments, tutorials, and information kiosk” (Zumbach et al., 2006, p. 286). The third level was for students to “be able to explore and to experiment” and the design strategies used to achieve this were to use “own experiments, background information, planning and reflecting” (Zumbach et al., 2006, p. 286). The fourth level was for students to “be able to exchange research questions and findings” and the design strategies used to achieve this were to “report research, establish community of practice, collaborative planning and reflecting” (Zumbach et al., 2006, p. 286). These virtual labs adapted learning to meet students at their current level of background knowledge and get different supports. The virtual labs are designed to collect student generated data and organize it for the students. These reports are then able to be modified and annotated by the learner. This type of design seems to give students scaffolds and feedback while allowing them to engage with activities as seen in science practices like designing experiments.
Existing virtual labs employ various design strategies. The designs of all virtual labs are the focal points of the lab, the cognitive load of the lab, scaffolds used in the lab, the amount of hybridization in the lab, the infrastructure of the lab, sense-making in the lab, constraints in the lab, the ability to differentiate instruction, the relevance of the lab, how to guide learners to interpret the data, the ability for students to ask questions, how much students need to use evidence throughout the lab, how students are able to design the investigations, how students can form and evaluate their explanation, and the ability for students to communicate their findings (Scalise et al., 2011). These design considerations were seen in at least one of the virtual labs studied in the literature (Scalise et al., 2011). Researchers have different ways of describing the virtual labs and the studies designed to evaluate the virtual labs (Scalise et al., 2011). Many of these areas of design focus were evaluated through the literature review and are reflected in The NRC Framework and NGSS.

Conclusion

As can be seen from this chapter there has been a significant amount of research on distance education, online learning, science learning, constructivism, and virtual labs. However, not a single study has explored the labs used in cyber charter schools for their potential to engage students in science practices and crosscutting concepts in a constructivist learning environment. This study fills a need by describing the labs used by students who are primarily completing their education online. Science education and scientific literacy are important for all students. Equity in science education is an important goal of the NRC Framework (Quinn et al., 2012). A research agenda on science education in cyber charter schools can provide a base on which to build studies that study the quality of the curriculum and specific labs in detail. Future studies that use qualitative and quantitative methods to describe, explain, and/or predict student experiences and
learning in these environments can also use this information to understand science education in this context.

The goal of this chapter was to review previous literature related to students doing science in an online environment in order to set the context and purpose for the current study. The concepts selected are related to factors that can affect how students perceive and learn from their virtual labs. Three previous studies employed forms of content analysis to specifically look at laboratory investigations (Chen, 2010; German et al., 1996) or curriculum materials (Kesidou & Roseman, 2002). The objective of each of these studies was to see how well these materials were helping students to meet the desired outcomes of science education.

Chen (2010) conducted a content analysis of 233 physics virtual labs to determine the type of scientific inquiry model represented. These labs were drawn from the PhET Web site which is widely available to educators. The analysis pointed to a majority of the labs using the hypothetical-deductive model of scientific reasoning and the lack of authentic results that this gives to the students. Chen (2010) warns that virtual lab designers need to consider employing a more holistic account of scientific inquiry so that the complexities of understanding science outside of school settings are experienced in school.

Constructivism is a commonly used theory to explain science learning and student-centered learning environments. In addition, as mentioned throughout this chapter, many cyber charter schools make statements about their curriculum on their Web sites that reflect ideals of constructivism and student-centered learning. Therefore, constructivism serves as the learning environment through which certain concepts are described in more detail such as reflection and metacognition, scaffolds and scripts, problem-solving, and active learning environments.
Distance education is the broader system where all cyber charter schools are housed. Cyber charter schools have differences between them but they all share the same feature of having students interacting with their teachers, peers, and curriculum from a distance (Raish & Carr-Chellman, 2015). Although the common conception may be that the educational experience of students in cyber charter schools is different than from students in traditional brick-and-mortar schools, numerous studies have shown that the media that students learn through does not have an impact on the effectiveness of the learning (Clark, 1983). However, the design of instruction does impact the effectiveness of that learning. This study is exploring the design features of these labs. In addition, the system can impact the learning experience (Moore & Kearsley, 2011). For example, students found the restricted access on certain Web sites very frustrating to their learning flow and experience in a hybrid charter school. The students would frequently try to go to Web sites that were ‘blocked’ for being games even if they were not (Raish et al., 2012).

Science laboratory investigations are an integral part of science curricula whether they are completed face-to-face or virtually. There are differences in science labs that are designed around scientific practices and inquiry than labs that are used to “illustrate, demonstrate, or verify known concepts and laws” (Fuhrman et al., 1978, p. 12). There have been multiple studies of virtual science labs that show they are as effective as face-to-face science labs (Klahr et al., 2007; Pyatt & Sims, 2011; Zacharia et al., 2008) but these studies only focus on conceptual change and ignore the other competencies that students can learn from science laboratory investigations. To succinctly organize all of these features that could be identified in a virtual lab, a framework and table are developed in the methodology to help organize the analysis of the labs.
Chapter 3

Methodology

This chapter locates the study within a chosen methodological approach, demonstrates the appropriateness of that approach, gives detail on the sample and the rationale for choosing its selection, and provide a thorough explanation of the data-collection and analysis procedures employed (Bloomberg & Volpe, 2012). These components together provide the reader with a fundamental understanding of how the study answered its research questions.

The organization of this chapter adheres to the following outline, as recommended by Bloomberg and Volpe (2012): (a) purpose statement; (b) rationale for the chosen research approach; (c) context for the research; (d) description of the research sample; (e) discussion of data-collection methods; (f) discussion of data-analysis methods; (g) credibility; and (h) limitations of study design. The chapter concludes with a section on researcher identity in order to note and acknowledge potential biases.

Purpose Statement

The purpose of this study is to explore the variety of labs in which cyber charter-school students participate and the potential for these labs to engage cyber charter-school students in science practices and crosscutting concepts. The constructivist supports built into the labs are also analyzed. This study is exploratory, and as such, emergent, and unexpected findings are expected.

The labs were observed and classified according to identifiable markers that offer the potential to engage students in science practices and crosscutting concepts. The labs were then analyzed according to their natural separation to identify these components. This varied depending on the design of the labs. For example, in one lab, students had to click when a
section was complete and that lab was analyzed in sections to identify the markers. In another lab, the interface was less directive of students, and this lab was analyzed in a more open-ended format that arose through my interactions with the lab and my understanding of how to control the variables.

Driving this research is a recognition that science labs are an important part of science education; in particular, labs help students to achieve science literacy. The laboratory experience for students in cyber charter-schools has not yet been studied. An appropriate first step was thus to analyze the labs themselves in order to understand their potential to engage students in science practices and crosscutting concepts.

To give rich descriptions to the data, the sample for this study is comprised of labs used by middle-school science students at select cyber charter-schools in Pennsylvania. This represents a new sample as prior research has looked at widely available physics virtual labs (Chen, 2010) but not within the context of schools using those labs and only from one lab provider (PhET). The sample was selected after conducting interviews with teachers and gaining permission from the schools to access the virtual labs. The student population using the labs has not been previously studied. This research is limited in the fact that it does not study the students who are using the labs. However, it provides a foundation for further studying the labs that students are using, their experiences with them, and the learning that takes place in the labs.

The narratives of the labs are illustrated with figures, descriptive text, and a simple numerical summary of the presence of various markers in the labs. In addition, interviews were conducted with teachers using the labs to contextualize the various experiences of the students. The interviews helped to identify themes across schools, as well as differences in how the schools use the labs. This helped to answer the first research question regarding variations
between the labs. It also helped to describe the structure of the cyber charter-schools and challenges the teachers face in conducting labs in a virtual environment.

**Research Questions**

The research questions addressed by this study are as follows: “What are the variations of labs that are in the cyber charter schools included in this study?, “Are there identifiable markers that are observed in the labs in cyber charter middle school-classrooms that have the potential to engage learners in science practices and crosscutting concepts?” and “Are there constructivist design components used in the labs to support the potential to engage students in science practices and crosscutting concepts?”

**Research Methodology**

The research methodology selected for this study, a combination of thematic analysis and qualitative ECA was driven by the research questions and sample studied. In practice, various research traditions and methodological choices do not fit within neatly defined boxes. Broadly speaking, quantitative research is interested in testing theories and determining relationships between variables using statistical methods (Creswell, 2013). Qualitative research, on the other hand, uses an interpretive lens to make meaning from the participant’s perspectives (Creswell, 2013). Qualitative research recognizes the complexity of situations and the subjective nature of interpretation (Merriam, 2002). Thematic analysis was used to analyze the teacher interviews (Braun & Clarke, 2006) because it is flexible and can be used with a variety of research approaches (Baptiste, personal communication, Qualitative Data Analysis 551, 2015). Qualitative ECA was used to analyze the materials of the labs. Previous studies analyzing curriculum materials, laboratory investigations, or virtual simulations all selected similar methods of analysis. Chen (2010), for example, investigated a similar sample – online physics
science laboratories for K-12 students – and identifies the chosen methodology as content analysis. Kesidou and Roseman (2002) employ a curriculum-analysis procedure and German et al. (1996) use a form of content analysis by employing an adapted version of the “Laboratory Analysis Inventory (LAI) developed by Tamir and Lunetta” (1978, p. 480). The present study uses qualitative, ECA for the content analysis and thematic analysis for the teacher interviews. The method of analyzing data is the primary factor in determining whether a study is qualitative or quantitative in nature, not the type of data collected. (Baptiste, 2001).

Thematic analysis (TA) is a strategy proposed by Braun and Clark (2006). TA was chosen for this study because of the strategy’s methodological flexibility and the relevance to the interviews conducted in this study (Braun & Clarke, 2006). It was important for this study to select an analytical technique not connected to a particular methodology as the analysis of the teacher interviews complements the ECA. The specific TA in this study is inductive as the teacher interviews are specific to this dataset; it is also semantic in that the teacher interviews are not intended to discover latent meanings in the data, but rather to provide context for the ECA to follow. There are six stages of TA, which include becoming familiar with the data, coding, naming themes, reviewing themes, and finally writing a paper using the themes (Braun & Clarke, 2006).

Content analysis can be either quantitative or qualitative. Quantitative content analysis focuses on sorting text into categories and counting the frequencies of certain phrases or words (Kohlbacher, 2006). Qualitative content analysis is primarily interested in the meaning behind the content or context (Hsieh & Shannon, 2005). Qualitative content analysis has its roots in the quantitative content analysis tradition (Schreier, 2012). Qualitative content analysis was originally focused on interpreting text. There are now multiple forms of media that can display
information which led to analysis beyond text. There are many different ways to employ qualitative content analysis as a methodology. Hsieh and Shannon (2005) identify conventional content analysis, directed content analysis, and summative content analysis as three such methods. All forms of qualitative content analysis pay “attention to unique themes that illustrate the range of the meanings of the phenomenon” (Zhang & Wildemuth, 2009, p. 2). In this study the phenomenon under investigation is the range of virtual labs that students complete in cyber charter-schools.

Ethnographic, directed content analysis was the methodology used for analyzing the virtual labs in this study. Directed content analysis is considered the middle ground between inductive and deductive content analysis. According to Elo and Kyngas (2008) inductive content analysis is used when (a) categories are derived from the data; and (b) little is known about a phenomenon. Deductive content analysis is used when there is already a substantial amount known about a phenomenon. Directed content analysis should be used when there is some prior information or theory about the phenomenon under investigation. Previous research that uses content analysis to look at inquiry in science labs includes German et al.’s (1996) analysis of laboratory manuals and Chen’s (2010) determination of the type of scientific reasoning represented in PhET virtual physics labs. In addition, there are a substantial number of studies that have defined the type of thinking and inquiry that should be represented in scientific investigations and activities for students, as well as the scaffolds needed for these designs (Belland, 2010; Duncan & Tseng, 2011; Edelson et al., 1999; Kali & Linn, 2007; Pyatt & Sims, 2011; Quintana et al., 2004; Rutten et al., 2007; Sharples et al., 2014; Svilha & Linn, 2012; van Joolingen et al., 2007; Varma & Linn, 2012; Zacharia et al., 2008). However, the previous studies do not take into account the setting of cyber charter schools; they also do not consider
that the NGSS has redefined scientific inquiry as science practices, and they do not focus on
science practices and crosscutting concepts. This study uses concepts found in previous studies
in order to generate new findings as well as to identify emergent phenomena. The studies
identified are used to refine existing categories important to constructivist design supports and
constructivist learning environments as established categories. The established criteria for
science practices and crosscutting concepts are adapted from Quinn et al., (2012).

** Appropriateness of Content Analysis**

Document analysis is “an integrated and conceptually informed method, procedure, and
technique for locating, identifying, retrieving, and analyzing documents for their relevance,
significance, and meaning” (Altheide & Schneider, 2013, p. 5). The word ‘document’ is typically
used to refer to “a piece of written, printed, or electronic matter that provides information”
(Google Definition, n. d.). The labs are electronic matter that provide information, and they thus
can be considered documents.

The labs analyzed in this study are those used by cyber charter-schools. Students who
study at cyber charter schools have different learning environments than students who study at
other types of schools and who have been analyzed in previous investigations. The labs are
analyzed with respect to more than their ability to promote students’ conceptual understanding.
A weakness of several previous studies is that they have focused on conceptual understandings in
science (de Jong et al., 2013) rather than students gaining competency with science practices and
crosscutting concepts. Students in cyber charter schools rely on various technologies to complete
their courses and communicate with their peers and instructors. These students are thus likely to
have a different experience completing labs and simulations than those students who complete
labs in a synchronous environment with close proximity to their peers and instructors. Therefore,
the previous conceptions and understandings of virtual simulations and scientific practices are insufficient to explain the phenomenon of labs in cyber charter schools. For example, in a face-to-face environment it is not as important if the labs have prompts, communication features, or reflection activities included, as these gaps can be relatively easy for a teacher to address. This study analyzes the communication features built into the various labs in order to identify the affordances and constraints offered by the labs to facilitate and help students to engage in evidence-based as a science practices of the NGSS.

ECA was developed because there was “an awareness by many researchers that simply studying the content of mass media was not enough” (Altheide & Schneider, 2013, p. 3). The shift to ECA in the 1990s resulted in communication formats no longer being seen as ‘resources’ but being seen as ‘topics’ to explore (Altheide & Schneider, 2013). Since then, there has been a recognition of the importance of information technology. Indeed, from 2000 to the present, there has been a tremendous increase in the number of information and communication technologies. This increase has transformed our understanding of the ways that individuals communicate, commonly known as media logic. Media logic suggests that: “information technology and communication formats shape how information is constructed, recognized, and interpreted in social interaction” (Altheide & Schneider, 2013, p. 4). Labs are designed in specific ways and their designs shape how the information they provide is interpreted by students. For example, one virtual lab may use adaptive technologies that personalize the feedback for students based on their responses; another lab, however, may not provide feedback at all. One teacher may use his or her webcam without asking students to articulate their thoughts on the lab, while another may create a video prior to the start of the lesson and then facilitate a collaborative discussion while the students are viewing the lab. Analyzing media logic can provide insights into how content
may be interpreted by students. The analysis of media logic is naturally interpretive as the analyzer is central to identifying how the information is interpreted... The analysis in this study is a form of media logic focused on specific components of that media.

In a traditional ethnography, researchers spend a significant amount of time in the field engaged in participant observation (Van Maanen, 2011). Ethnographic content analysts do not spend time engaged in participant observation. Rather they immerse themselves in documents (Altheide & Schneider, 2013). Nevertheless, ethnographic research is fundamentally social and acknowledges the constant revision of beliefs and understandings (Altheide & Schneider, 2013).

Content analysis is an appropriate methodology to use when there is a need to compare types of media (Weber, 1990). The labs in this study are discussed individually and presented as school case studies alongside their descriptive summaries. After all of the labs were analyzed, frequency counts were completed in order to provide a numerical summary of the presence of science practices, crosscutting concepts, and constructivist supports, suggesting the labs’ potential to engage students with these practices and concepts. These are included here to provide a snapshot of the labs as a whole as a means of showing similarity and difference between these findings and previous findings.

The research goal in ECA is discovery and verification. As such, a directed approach was used in the development of this study’s framework, and the study included the discovery of emergent findings and verification of existing findings. ECA is reflective and circular, and it involves the researcher at all points of the research process (Altheide & Schneider, 2013). Directed content analysis leads to the development of some categories with the expectation that more will emerge throughout the analysis (Hsieh & Shannon, 2005). In ECA data can be presented in both textual and table formats alongside both textual and statistical analysis.
The results chapter includes both textual and statistical analysis. The data were subject to researcher interpretation. This means of interpretation is recognized as good research in qualitative content analysis (Altheide & Schneider, 2013) and qualitative research (Lincoln, 1995). There are many activities and processes associated with completing a lab and content analysis was used as a strategy to pare the activities, simulations, and texts into a manageable number of categories (Weber, 1990). For example, a virtual lab might require students to set-up the equipment for the experiment. While this is part of the overall lab, the specific feature of setting-up the lab could be analyzed with respect to the crosscutting concepts, science practices, and constructivist supports the labs includes for the students. One such constructivist support could be a personalized environment determined based on prior knowledge; the science practice could be planning/carrying out investigations; and the explicit crosscutting concept could be structure and function. While studying and describing equipment set-up, other features considered important when the student completes the lab such as the clear completion of steps, emerge that are not accounted for initially, such as the lack of mutual exclusion between virtual experiments and observing simulations.

Content analysis should be used when “the aim is to attain a condensed and broad description of the phenomenon” (Elo & Kyngas, 2008, p. 108). There is no right way to perform content analysis; rather, strategies need to be selected that make the most sense for the research questions and the sample under investigation (Weber, 1990). The directed content analysis used in this study classifies the markers of the labs according to a preliminary framework broadly identified in Figure 3.1 and more explicitly delineated in Table 3.1. Markers unaccounted for by this framework also emerged during the study. This data is credible as it does not matter what the source of data is for qualitative content analysis. Data created by the researcher while
manipulating the lab is just as valid as data that already exists in the form of a document (Schreier, 2012).

**Limitations of Content Analysis**

All studies have limitations that result from methodologies used, the data collected, and the analysis techniques employed. Similar to other qualitative studies, this study suffers from limitations of generalizability (Golafshani, 2003). However, because the labs existed before the study, the generalizability of ECA differs from notions of generalizability in phenomenology, ethnography, narrative, and grounded theory. The primary data for the ECA in this study was not generated from research participants; rather, it was, produced during the researcher’s workup and analysis of the labs. The labs analyzed are used by thousands of students across Pennsylvania. Since there was no interaction with students using the labs the results are not limited to those students. This generalizability is more likely to be seen in purchased curricula, as these are the same across all cyber charter schools that use the software, unlike localized teacher-designed curricula, which are unique and rely on local design work. The teacher interviews that provided context for the lab limited the generalizability of the findings. Limiting the generalizability of this study are the teacher interviews that led to the contextual descriptions of the labs and the identification of the labs used in the various courses. There is more than one way to interpret and analyze the media chosen (Krippendorff, 2012) and the findings of this study are not the only conclusions that could have been drawn about the scientific practices and crosscutting concepts used in the labs. In addition the virtual labs could have been analyzed according to other frameworks or theories. Artificial limitations need to be in place to focus the study (Schreier, 2012). Yet these narrow the perspective of the study in such a way that potential findings may be
missed. For example, the analysis of core ideas as part of the NGSS with science practices and crosscutting concepts are not emphasized on in this study.

It is recommended that more than one researcher is involved in the coding process of content analysis (Guthrie, Petty, Yongvanich, & Ricceri, 2004). However in this study I was the only researcher analyzing the data. This infers that independent researcher subjectivity plays a significant role in the interpretation of the findings. This interpretive research lends to the subjective nature of reality and aligns with my ontological views of the world. A limitation of this strategy is that I could become ‘stuck’ within the themes that are generated (Walsham, 2006). Quantitative conceptions of content analysis were considered research when they addressed “true knowledge with numbers and measurement” (Altheide & Schneider, 2013, p. 9). ECA diverges from traditional notions of content analysis by incorporating and embracing the subjectivity of the researcher. This acknowledgement is recognized as good research (Altheide & Schneider, 2013). This study does not analyze student work produced during the labs, interact with students who complete the labs, or perform any sort of experimental studies on learning gains before or after the labs.

An important distinction needs to be made between qualitative content analysis and other forms of qualitative research. Qualitative content analysis allows the researcher to describe a particular phenomenon from a chosen perspective. According to Schreier (2012), qualitative content analysis does not take a hermeneutic perspective. Hermeneutic methods allow the researcher to arrive at a more complete understanding of the phenomenon as a whole, whereas qualitative content analysis allows for a focus on specific parts of a phenomenon, as collected in the data (Schreier, 2012). While a comprehensive picture emerges after describing all parts of the lab, the experience of using labs in cyber charter schools is not described. Qualitative content
analysis requires that the researcher focus on specific attributes of the content and ignore others (Altheide & Schneider, 2013; Schreier, 2012). As the analytical process begins and categories emerge, the coding frame changes but the categories remain focused on specific features in the content analysis and do not provide an overall picture of that phenomenon (Schreier, 2012). For example, there may have been aesthetic factors in the labs that affected how students perceive and interacted with the material but these were not studied. The ideal length of a video or simulation was not analyzed in terms of learner focus or zone. In addition, the learning supports were not analyzed from the perspective of a learning theory beyond constructivism. Another difference between qualitative content analysis and other forms of qualitative research is in the inferences made regarding the data collected. When the data is collected from already existing documents, as it was in this study, it is important to describe the context in which these documents exist. The descriptions of cyber charter schools and interviews with teachers helped to contextualize the documents.

**Unit of Analysis**

The unit of analysis used in qualitative content analysis is a particular theme related to the phenomenon under investigation. Altheide and Schneider (2013) state that “the research problem helps inform the appropriate unit of analysis” (p. 39). In this type of analysis the length of text, or in this case the simulation or demonstration, is not important it is the appearance of the theme that is significant (Zhang & Wildemuth, 2009). Therefore, the unit of analysis in this study is the content that appeared in the labs related to scientific practices, crosscutting concepts, and constructivist supports. Each lab was analyzed according to the particular units that made sense for it. This unit varied by lab and emerged during the analysis. For example, some labs had procedures for students to follow, while others were more open-ended. Some labs had multiple
‘pages’ appear for the students while others took place entirely in one simulation. In other words, the design of the lab directed the unit of analysis. If the teacher supplied a worksheet this also impacted how the content was analyzed to divide the analysis into manageable components. Based on steps three through eight of the ECA the unit(s) to constrain analysis were identified. There was a matrix of various concepts to explore from previous literature with emergent findings listed at the bottom of Table 4.4 and 4.5. The categories are presented in tabular form with textual descriptions to account for the findings in more detail.

A spreadsheet outlining the concepts and supports that were used to guide the existing constructivist features in the design of the labs is seen in Table 3.1. Some of the labs had slides that students were to complete while other labs were contained in one window. Each lab’s unit of analysis emerged during the ECA and was dependent on the design of the lab. However, the unit of analysis was always related to either a science practice, crosscutting concept, or constructivist support. For example, ill-structured problem-solving was identified as a component of the constructivist learning environment based on the defining criteria of an ill-structured problem. The lab had to have a problem that had multiple solutions and the lab could not identify the precise procedures that needed to be completed in order to fully count as an ill-structured problem. The cumulative codes from each lab are seen in matrix form in Tables 4.4 and 4.5.

According to Merriam (2009) a model serves as a “visual presentation of how abstract concepts (categories) are related to one another” (p. 189). However, due to the pre-existing understanding of the word ‘model’ in science education literature, the word ‘framework’ is used in this study. The framework pictured in Figure 3.1 and Table 3.1 helps to provide a structure through which to identify the various components of the virtual labs. These frameworks identify
the existing categories that are identified through analysis of the virtual labs.

**Figure 3.1.** The science practices, crosscutting concepts, and constructivist design components analyzed in this study

**Table 3.1**

**Concepts Identified as Important to Design**

<table>
<thead>
<tr>
<th>Constructivist Design and Learning Environment Components</th>
<th>Description</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication features (peer-peer and peer-instructor, peer-content)</td>
<td>Features built into the lab to support communication with peers, instructor, or ‘presence’ in the lab that provides feedback to the students</td>
<td>Hoadley (2000), Quinn et al., (2012), Rummel &amp; Spada (2012)</td>
</tr>
<tr>
<td>Descriptive sequences, scripts</td>
<td>Varying levels of descriptives and indexicals in the labs</td>
<td>Luckin (2008), Wettstein (1979)</td>
</tr>
<tr>
<td>Scaffolds present (fading, channeling, modeling)</td>
<td>Support learner just beyond current ability, fade when support is no longer needed, channel students to focus on important part of task and model the task.</td>
<td>Jonassen, (1999), Pea (2004), Puntambekar &amp; Hubscher (2005)</td>
</tr>
<tr>
<td>Metacognition</td>
<td>The prompts start with “What do you know about, or a question like “How do you know this? Essential feature of metacognitive prompts – diagnosis, calibrated support, fading, and individualization. Focusing students on which variables to control, probing questions and support for asking which variables to control.</td>
<td>Azevado &amp; Hadwin (2005), Flavell (1979),</td>
</tr>
<tr>
<td>Reflection</td>
<td>Leads with prompts such as – reflect on what you have just done, connect this to something you learned in class, is this how you thought this works, what is your prior knowledge related to this task. Does this data match your hypothesis? Justify your answer. Right now, we’re thinking. Reflective prompts need to have feedback with them based on the student answer.</td>
<td>Ash &amp; Clayton (2009), Bannert (2006); Bransford et al., (1999); Davies (2003), Edelson &amp; Reiser (2006), Sandoval &amp; Reiser (2006), van den Boom, 2004)</td>
</tr>
<tr>
<td>Sense-Making</td>
<td>Asking students to form hypothesis, make sense of the material, compare, collect data, analyze the data, and communicate the data. Sense-making areas of the virtual labs require students to represent what they think about a task. Sense-making prompts ask questions like what part of the lab are you working on now, how does this hypothesis relate to your data, does this make sense based on what you have done. Providing data for their claims and arguments.</td>
<td>Bransford et al., (1999); Quintana et al., (2004), Sandoval &amp; Reiser (2006);</td>
</tr>
<tr>
<td>Distributed learning support (other than scaffold)</td>
<td>Any learning support that cannot be identified as a scaffold. It does not fade when no longer needed, doesn’t channel students to an important part of the task, or doesn’t model the task</td>
<td>Gott, Lesgold &amp; Kane (1996), Vrasidas (2000), Wilson (1996)</td>
</tr>
<tr>
<td>Independence</td>
<td>How free the learner is to make decisions in the virtual lab. Example: choosing how and in what order to manipulate the variables, choosing the proper size of equipment rather than it already being selected for the students</td>
<td>Vrasidas (2000)</td>
</tr>
<tr>
<td>--------------</td>
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<td>----------------</td>
</tr>
<tr>
<td>Cognitive tool</td>
<td>Tool that helps students amplify and externalize their thinking</td>
<td>Jonassen et al., (1999), Van Joolingen et al., (2007)</td>
</tr>
<tr>
<td>Authentic activities</td>
<td>The cognitive tasks students do are similar to the cognitive tasks that experts in the field do</td>
<td>Honebein, (1996), Jonassen (1999), Zumbach et al., (2006)</td>
</tr>
<tr>
<td>Presenting material from more than one perspective/modality</td>
<td>How many ways does the lab present a topic to the student? Do they read about it and see a simulation or only read about it?</td>
<td>(Black &amp; McClintock, 1996; Honebein, 1996; Jonassen, 1999).</td>
</tr>
<tr>
<td>Confounding variables</td>
<td>Controlled/Not controlled by the lab. Contributes to a well or ill-structured problem set</td>
<td>Chen &amp; Klahr (1999), Quinn et al., (2012),</td>
</tr>
<tr>
<td>Learner-context interaction scripts</td>
<td>Scripts that allow learners to build personal knowledge and meaning from the lab</td>
<td>Ally (2004)</td>
</tr>
<tr>
<td>Learn content to solve a problem</td>
<td>Learning through problem-solving</td>
<td>Jonassen (1999)</td>
</tr>
<tr>
<td>Ask about prior knowledge</td>
<td>At the beginning of the lab to find out what students know and not know and to help them externalize their thinking</td>
<td>Seimars (2012), Zumbach et al., (2006)</td>
</tr>
<tr>
<td>Acknowledging complexity of empirical work</td>
<td>Virtual labs can reduce complexity of empirical work, acknowledge that it is more complex than it appears</td>
<td>Crippen et al., (2012)</td>
</tr>
<tr>
<td>Support</td>
<td>Resources in the labs so that students can successfully complete the lab</td>
<td>Anderson (2008) m Puntambekar &amp; Hubscher (2005), Wilson (1996), Zumbach et al., (2006)</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Control</td>
<td>Ability to manipulate and design experiments, design various experimental set-ups</td>
<td>Vrasidas (2000)</td>
</tr>
<tr>
<td>Response to Learner Actions</td>
<td>When the learner does something in the lab the lab needs to respond and acknowledge that learners action. Gives learners clear and consistent feedback</td>
<td>Davis (2003), Gott et al., (1996), van den Boom et al., (2004)</td>
</tr>
<tr>
<td>Active Learning Environments</td>
<td>Allow learners to work at their own pace and require them to interact with the simulation in some way to see a response and feedback on their action</td>
<td>Jonassen et al., (1995), McCombs &amp; Vakili (2005), Tucker (2007)</td>
</tr>
<tr>
<td>Scripts</td>
<td>All virtual labs will have a script. The script will be described as providing more or less independence to the learner, and interactions the learner is using – learner-task, learner-learner, learner-expert</td>
<td>Jonassen (1999), Tsovaltzi et al., (2010)</td>
</tr>
<tr>
<td>Problem-Solving</td>
<td>Either well-structured or ill-structured problem – well-structured constrained, convergent solutions, ill-structured – multiple solutions, uncertainty, allow for error, ill-structured problems – more independence for the students. Ask questions such as about how would you solve this problem? Is there more than one way to solve this problem</td>
<td>Chin &amp; Chia, (2005), Jonassen (1999), Shin et al., (2001)</td>
</tr>
<tr>
<td>Explicit Awareness of Learning Goals</td>
<td>Explains to students why they are doing what they do, what they should learn at the conclusion of the virtual lab</td>
<td>Flavell, (1979)</td>
</tr>
</tbody>
</table>
The framework in Figure 3.1 was created from two of the three strands emphasized by the *NRC Framework* and the *NGSS*. The constructivist design features included in the framework come from previous literature on the design of constructivist learning environments (Black & McClintock, 1996; Honebein, 1996; Jonassen, 1999; Vrasidas, 2000; Wilson, 1996) and the design of science software for students (Chin & Chia, 2006; Duncan & Tseng, 2011; Edelson et al., 1999; Kali & Linn, 2007; Krajcik & Blumenfeld, 2006; Quintana et al., 2004; Sandoval & Reiser, 2004; Sharples et al., 2014). Science practices and crosscutting concepts were explored in-depth as part of the conceptual framework. The core ideas from the NGSS were not a central part of the analysis. Schreier (2012) emphasizes that choices need to be made regarding what to analyze in a content analysis. In this case, the core ideas were used as a way to describe and contextualize the sample. The labs in this study are not analyzed with respect to how conceptually accurate they were. Rather, they were classified according to their core ideas...

Many studies have investigated students’ conceptual development while completing virtual labs, but these studies have not considered the scientific practices or crosscutting concepts associated with the labs (Klahr et al., 2007; Pyatt & Sims, 2011; Zacharia et al., 2008). This study addresses the gap in the literature considering science practices and crosscutting concepts rather than ideas that have been studied elsewhere.

<table>
<thead>
<tr>
<th>Type of Lab</th>
<th>Simulated – do not prep equipment, Virtual – allow students to prep equipment for the virtual lab</th>
<th>Observation or Interaction Virtual and at-home blended</th>
<th>Crippen et al., (2013), Scalise et al., (2011)</th>
</tr>
</thead>
</table>
Design of Study

The design of any research study should be planned so as to best answer the research questions through appropriate sampling strategies, data-collection techniques, and analytical methods. In directed qualitative content analysis, the goal is to use existing theories as a basis for analyzing the content, while also allowing for themes and findings to emerge organically from the data (Hsieh & Shannon, 2005). In ethnographic qualitative content analysis the goal is to “document and understand the communication of meaning, as well as to verify theoretical relationships” (Altheide, 1987, p. 68). The role of the researcher is paramount in ECA, with ECA considering the context of the message in analyzing that message (Altheide, 1987). This study combines the use of existing theories from directed content analysis with ECA. ECA is an appropriate choice for the design of this study because it emphasizes the constant comparative method used to consider the labs while simultaneously allowing for categories to emerge from the data (Altheide, 1987) that are unaccounted for by the initial framework.

Previous studies investigating the nature of inquiry represented in science laboratory investigations have been designed to determine either the type of inquiry represented (Chen, 2010) or how well such science labs meet the criteria of the laboratory analysis inventory (LAI) (German et al., 1996). The research questions addressed by this study “What are the variations of labs that students participate in in cyber charter-schools?”, “Are there identifiable markers that are observed in the labs in cyber charter middle school classrooms that have the potential to engage learners in science practices and crosscutting concepts?”, and “Are there constructivist design components used in the labs to support the potential to engage students in science practices, and crosscutting concepts?” are different than previous research questions asked of virtual labs.
This study identifies markers related to a science practice, crosscutting concept, and constructivist supports and discusses the potential the labs have for engaging students in those practices and crosscutting concepts. Although existing categories were used to classify components of the labs, the research process allowed for iterative and emergent findings from the labs. An ECA and directed content analysis expects that there will be emergent themes from the data. (Altheide, 1987; Hsieh & Shannon, 2005) and there were indeed emergent themes in this study.

The general steps of an ECA are: (a) define a topic; (b) complete ethnographic study or literature review; (c) explore a few documents; (d) draft protocol; (e) examine documents; (f) revise protocol; (g) analyze theoretical sample; (h) collect data; (i) code data, (j) compare items; (k) complete case studies; and (l) write report. (Altheide & Schneider, 2013, p. 19). These steps help to structure an ECA. The drafting of protocol is the process during which the science practices, crosscutting concepts, and constructivist supports were identified as described above. The collection and comparison of the data depended on the unit of analysis selected (Altheide & Schneider, 2013). In this case the unit of analysis was related to one component or emergent component identified during the analysis of each lab. For example, at Cyber Charter School B the students had a script to follow for a blood-typing lab and each step the script has includes analyzed for themes related to the research questions.

The specific steps taken to analyze the labs are detailed in Table 3.2. These steps align with the suggested procedure for an ECA. The third column is the step in ECA that matches the more specific step for this particular study. The final column is a brief description of the ECA step as adapted from Altheide and Schneider (2013).

Table 3.2
### Ethnographic Content Analysis Aligned with This Study

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Alignment with ECA</th>
<th>Brief Description of ECA Step</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td>Identify the virtual labs that are going to be analyzed in accordance with the teacher interviews and core ideas of NGSS.</td>
<td>Topic</td>
<td>Choose the problem</td>
</tr>
<tr>
<td><strong>Step 2</strong></td>
<td>Gain access to the virtual labs from the student view.</td>
<td>Ethnographic study</td>
<td>Familiarize oneself with the content and context of the phenomena</td>
</tr>
<tr>
<td><strong>Step 3</strong></td>
<td>Run through various labs in the software to become accustomed to the structure of the labs</td>
<td>A few documents</td>
<td>Become acquainted with the phenomena studied by noting the structure of</td>
</tr>
<tr>
<td>Step</td>
<td>Description</td>
<td>Method</td>
<td>Notes</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Step 4</td>
<td>Complete the virtual labs in the same manner that a student would.</td>
<td>Ethnographic study</td>
<td>Familiarize oneself with the content and context of the phenomena</td>
</tr>
<tr>
<td>Step 5</td>
<td>Test the existing model against one lab from each school site.</td>
<td>Draft protocol</td>
<td>Create model used to categorize data</td>
</tr>
<tr>
<td>Step 6</td>
<td>Repeat completing the virtual lab while applying the scientific model to the virtual lab.</td>
<td>Examine documents</td>
<td>Testing the model created</td>
</tr>
<tr>
<td>Step 7</td>
<td>Identify various components of the virtual lab that fit with different parts of the model.</td>
<td>Examine documents</td>
<td>Testing the model created</td>
</tr>
<tr>
<td>Step 8</td>
<td>Revise the model against the virtual labs that have been analyzed</td>
<td>Revise protocol</td>
<td>Revise the model based</td>
</tr>
<tr>
<td>Step 9</td>
<td>Examine the theoretical sample of virtual labs (four virtual labs, one from each school).</td>
<td>Theoretical sample, Examine documents</td>
<td>Purposefully sample from the virtual lab and test the model created.</td>
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<tr>
<td>Step 10</td>
<td>Collect data from each of the virtual labs according to the refined model from the testing and examining of four virtual labs. After fifteen of the virtual labs have been collected, analyze the data to check for alignment with the model.</td>
<td>Collecting data</td>
<td>Collect data from each of the virtual labs, iterative process with analysis</td>
</tr>
<tr>
<td>Step 11</td>
<td>Identify any parts of the model that do not account for a phenomena of the virtual lab.</td>
<td>Revise protocol</td>
<td>Revise the protocol with any emergent findings not accounted for</td>
</tr>
<tr>
<td>Step 12</td>
<td>Categorize the findings from multiple virtual labs into themes according to the model.</td>
<td>Code Data</td>
<td>Code the data according to specific themes</td>
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<tr>
<td>Step 13</td>
<td>Repeat the virtual lab and note emergent findings/features not seen in the established model.</td>
<td>Examine documents</td>
<td>Examine the virtual labs again to note any findings not previously seen</td>
</tr>
<tr>
<td>Step 14</td>
<td>Constantly compare the recently analyzed virtual lab against the framework and other virtual labs.</td>
<td>Compare items</td>
<td>Engage in comparing items to analyze the data collected</td>
</tr>
<tr>
<td>Step 15</td>
<td>Complete a brief summary noting the characteristics of each virtual lab to create a concise case study</td>
<td>Case studies</td>
<td>Create brief summaries noting the characteristics, extremes, and general gist of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>the sample collected to immerse oneself in the data</td>
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<tr>
<td>Step 16</td>
<td>Report on findings.</td>
<td>Report</td>
<td>Report on analyzed data in context of relevant literature</td>
</tr>
</tbody>
</table>

Note: Interpretation of ECA connected to this study

Traditional, quantitative concepts such as generalizability, reliability, and validity are not appropriate for the goals of qualitative research (Lincoln & Guba 1985). This has led to the critique that qualitative research is not sufficiently rigorous. Yet in qualitative content analysis validity is recognized as an important goal. Validity in qualitative content analysis refers to the data-collection instrument. According to Schreier (2012) validity is defined as “an instrument is considered valid to the extent that it captures what it sets out to capture. A coding frame is valid to the extent that the categories adequately represent the concepts under study” (p. 175). Though it follows the steps for ECA suggested by Altheide & Schneider (2013) the framework for analyzing the data was reviewed and modified based on completion of the virtual labs from the student perspective. This increased the validity of the coding scheme because I was central to identifying the categories found in the labs and was able to generate deeper understandings of the labs since they were completed more than once. Each lab was typically completed twice but if it
was felt that two times was insufficient for understanding the markers in a given lab, the relevant parts of the lab were repeated. This occurred principally in open-ended lab environments like PhET™ rather than in more structured environments like the osmosis and diffusion egg lab from cyber charter school D.

One particularly specific criticism of the validity of qualitative content analysis is validity in interpreting latent content. Latent content has less “standardization, directness” and a higher “number of meanings” than manifest content (Schreier, 2012, p. 177). When analyzing latent content it is important to contextualize the content (Schreier, 2012). Therefore, another design component of this study was to interview teachers who were using the labs in their classrooms. While the main concern of this study was the science labs and their markers of science practices, crosscutting concepts, and constructivist supports, the interviews helped to contextualize the labs within the broader student experience. To that end interviews were conducted with a minimum of one teacher at each school site who was using the labs in class. The interviews took between thirty minutes and one hour and were all recorded using Audacity and conducted via a video conferencing system. Zoom and AdobeConnect were used, depending on the technology available in the room that the given teachers taught in in his or her schools. The goal for the interviews were to understand (a) how the teacher was using labs; (b) what the cyber charter school expected from the students in terms of communication in the labs and class; and (c) common challenges with using the labs. The rationale behind the communication questions in the interviews is that communication and interaction are emphasized in constructivist distance learning environments (Jonassen et al., 1995) and the amount of interaction used in conjunction with the labs cannot be determined by solely analyzing the labs. The labs were analyzed for their ability to support communication but the teachers were also asked how they communicate about
the labs. The teachers’ interviews were analyzed using thematic analysis (Braun & Clarke, 2006). Therefore, the units of analysis for the teacher interviews were (a) responses contextualizing the labs; (b) responses related to how students communicate in the labs; (c) responses related to identifying frequently used labs; and (d) the teachers’ definitions of experiments and labs for cyber charter school students.

**Research sample.** One of the differences between quantitative and qualitative data analysis is in the selection of the sample. The samples selected for this research are comprised of “purposely selected texts which can inform the research questions being investigated” (Zhang & Wildemuth, 2009, p. 2). Content analysis is an especially appropriate methodology for my sample because it entails a “systematic reading of a body’s texts, images, and symbolic matter, not necessary from an author’s or user’s perspective” (Krippendorff, 2012, p. 10). The sample of labs selected from five cyber charter schools using different labs (only one of which was overlapping between two schools) and that were willing to participate in the study, provides a look at the material that a significant cyber charter-school student population are using. The sample was identified via interviews with the teachers access to the curriculum used in that cyber charter school. The teachers identified labs that they frequently used. The core ideas and standards from the NGSS were selected for each lab to contextualize the lab in a content area. The original intention was for teachers to identify these labs but through conversations with the teachers it was clear that not all of them were familiar with the core ideas in the NGSS. Accordingly, not every core idea was covered, and some core ideas included multiple labs. While a diverse sample was targeted it was not always possible to obtain such a sample with the core ideas. For example Cyber Charter School E had more labs in its first lessons and these labs typically related to fundamental science practices rather than specific life or physical sciences
content. The labs were generalizable to all students who could use them. The caveat, however, is that the teachers’ descriptions of the labs were limited to their specific contexts. The interviews with teachers using the labs helped to contextualize the students’ experiences and provide a more systemic view of the labs in action. The decision to adopt a more systemic view was influenced by Moore and Kearsley’s (2011) emphasis on a systems view in distance education, as well as the importance of contextualizing the latent content (Schreier, 2012).

**Data collection.** The primary data-collection artifacts in this study are the labs that the students completed. As part of this collection process, screenshots were taken of each lab in order to provide a visualization of the interpretation process and illustrate the labs. It took approximately 90 minutes to analyze each virtual lab after completing the lab two times and was becoming comfortable with categorizing what had been seen in the labs. This meant approximately six hours per school. Interviews were conducted with a teacher at each school site who was using the virtual labs. Cyber Charter School C facilitated a group interview with three teachers as they all taught the same course, albeit in slightly different ways. The interviews were between 30-60 minutes each. According to Merriam (2009) collecting documents is not drastically different than conducting interviews or collecting observation data and this was true in this study. Finding a sample, building rapport, familiarizing myself with the data, and making meaning from the data were all a part of this study.

**Visual media collection.** Although the documents collected in this study are not documents in the traditional sense of text-based material, they are still a form of material that conveys information. There were a total of 20 labs analyzed in relation to their markers in order to identify the labs’ various components as a science practice, crosscutting concepts, or constructivist supports. One of the limitations of data collection is that since the documents, or in
In this case, labs, are already in existence they have not been created specifically for research purposes (Merriam, 2009). However, the same can be said for other educational technologies like digital badges intended for instruction, which may be used for content analysis in future research.

**Interviews.** The interviews in this study serve to contextualize the labs. Moore and Kearsley (2011) believe that distance education should be viewed from a systemic perspective. The labs are only one piece of the cumulative educational experience for the students but by gaining the perspective of teachers who are using the labs, the labs are able to be contextualized in the classrooms in which they are used. The teacher interviews are primarily structured around building descriptions for the labs, having the teachers define how they conceive of labs or experiments in their cyber charter-schools, considered any challenges or issues that the teachers have encountered with using the labs, discussing any solutions that have been created in response to these issues, and extending the social or communicative practices that are associated with the labs. The first of these points contextualizes the labs. The second point was added after the first two interviews it was realized there was not a clear understanding of how a “lab” is defined in a cyber charter school. The third and fourth points were designed to elicit discussion about common practical problems with using labs in cyber charter schools, and the fifth point was informed by constructivist theories about how labs look in middle-school cyber charter classrooms.

**Data Analysis**

According to Krippendorff (2012), ECA “encourages content analysis accounts to emerge from readings of texts” (p. 23). In the ECA tradition, constant comparative techniques are used to analyze the data (Altheide, 1987). A very thorough description office analysis appears on page 67 of Altheide’s (1987) foundational text. Table 3.2 addresses the design of the
study and elaborates on the specific steps of ECA as they relate to this study. The research goal of ECA is both discovery and verification of the data. In this sense, directed content analysis blends well with ECA. There are already theories, models, and descriptions of virtual labs but are not of the labs in cyber charter schools. These theories, models, and descriptions also have not considered the labs that these students are using from the perspective of this study. Therefore, these theories and models may or may not be appropriate for describing these labs. There are some prestructured categories within directed ECA, but ECA still allows for categories and codes to emerge from the data (Altheide, 1987). The framework created in Figure 3.1 for evaluating the labs is iterative and meant to serve as a guide for focusing the study on the research questions using the steps outlined by Atheide (1987) in Table 3.2. The initial analysis of the labs was reflexive and occurred at the same time that the data was collected, coded, conceptualized, and interpreted (Altheide, 1987).

The constant comparative method was used to analyze the data and form conceptions and categories (Boeije, 2002; Glaser, 1965). Due to using directed content analysis, the initial constant comparative technique was used Figure 3.1 and Table 3.1. The steps outlined in Table 3.2 sequence the iterative steps in the study. Figure 3.1 and Table 3.1 were created in response to the research questions. Figure 3.1 is brief but the more thorough descriptions in Table 3.1 of all of these concepts in the conceptual framework were used to identify those markers of the labs. After one virtual lab was analyzed and initially coded, the next lab was compared to both the initial framework and to the first virtual lab analyzed and coded. The labs were constantly compared to ensure the validity of the research findings. Merriam (2009) notes that “coding is nothing more than assigning some sort of shorthand designation to various aspects of your data so that you can easily retrieve specific pieces of data” (p. 273). At the conclusion of initial data
analysis, a framework was generated to reflect what was seen in the labs with regards to the science practices, crosscutting concepts, and constructivist supports.

Although ECA uses the constant comparative method that emerged from grounded theory methodology, the primary goal of ECA is not to develop a theory. Rather ECA “is more comfortable with clear descriptions and definitions compatible with the materials, which can help generate concepts appropriate for theoretical testing” (Altheide & Schneider, 2013). The process of comparing and contrasting cases occurs throughout of an ECA. Data analysis in ECA is bolstered by the researcher’s present knowledge of the topic under consideration. In this case, a framework derived from previous research on virtual labs, science practices, crosscutting concepts, and the design of constructivist learning environments provided a knowledge base for what could hypothetically be found in an ideal virtual lab (Altheide & Schneider, 2013), in addition to my experience as a biology major and middle-school life and earth-science teacher in a hybrid charter school. ECA qualifies as a directed content analysis because there are already some theories, tenets, and characteristics of the phenomenon described in the literature (Hsieh & Shannon, 2005).

The process of arriving at categories or overarching themes during the data collection is inductive in nature (Merriam, 2009). In contrast, after the data has been analyzed to a point of saturation, the process is deductive, focusing on ensuring consistency and conformability across the data sets (Merriam, 2009). The results of the data analysis produced a narrative of the phenomenon supported by numbers (Altheide, 1987; Krippendorff, 2012).
Credibility of Qualitative Research

There have been several efforts to establish the strength, rigor, and validity of qualitative research (Creswell, 2013; Denzin, 2009; Krefting, 1991; Patton, 2005). There are three major criticisms of qualitative research: that it is subjective, that it is not reproducible, and that it does not enable generalization in the same way quantitative research does (Mays & Pope, 1995). Barbour (2001) asserts that one of the best ways to respond to criticisms of qualitative research is to fully embrace the qualitative tradition and ensure that any research undertaken is consistent in its use of appropriate methodologies and interpretations. This involves being extremely thorough in describing the methodologies and data-analysis techniques used (Mays & Pope, 1995). While this can be problematic in a journal article with word-count limits, a qualitative dissertation can be extremely thorough in describing its methodological choices. One of the objectives of this chapter was to provide a thorough of the study’s methodology. Another strategy to ensure rigor and trustworthiness in qualitative research is to be selective in choosing a sample. In qualitative content analysis the goal is to describe the various ways that the phenomenon is represented (Zhang & Wildemuth, 2009). While this study is not able to evaluate all of the virtual labs in cyber charter schools, the chosen sample was carefully selected to represent the phenomenon under consideration.

Researcher Identity and Subjectivity

Objectivity is not possible in qualitative research. As such, it is important to acknowledge and reflect on existing biases, conceptions, and understandings of the phenomenon being explored. This is aptly described by Krippendorff (2012) when he states that “the analysts acknowledge working within hermeneutic circles in which their own socially or culturally conditioned understandings constitutively participate” (p. 23). By acknowledging my identity as
a researcher and any potential biases that I bring to the study, I strengthened the study’s validity and reliability. According to Merriam (2009) “critical self-reflection by the researcher regarding assumptions, worldview, biases, theoretical orientation, and relationship to the study” (p. 229) can also help to strengthen my qualitative research study. As Merriam (2009) notes it is not a negative that “the researcher is the primary instrument for data collection and analysis” because “humans are both responsive and adaptive” (p. 160) and thus able to manage emergent findings in research studies. The researcher’s focus shapes meaning constructed from the document, and it will be different than if another researcher looks at the same set of documents with a different focus.

I became interested in online learning through my experiences as a Master’s student earning my degree through a dual-mode institution. This positive experience exposed me to some of the design considerations and pedagogical implications of teaching at a distance. I am interested in science education because my bachelor’s degree was in biology and I have enjoyed learning about and teaching science in the past.

These two experiences allowed me to apply for and gain employment as a middle school science teacher in a hybrid charter school environment. Although the school was technically a hybrid between online and face-to-face learning I taught all students through the computer, even those who were physically present in the same building as me. Even though I had recognized that teaching science to middle-school students in an online environment might be difficult, I was not prepared for trying to model inquiry for students with preselected laboratory curriculum that did not effectively approximate the experience I was envisioning. After seeing that the curriculum software was primarily composed of ‘cookie-cutter’ laboratory experiences that did not require students engage in open-ended inquiry or given the locus of control for the study, I attempted to
rectify the situation by using virtual and physical materials that better matched the nature of scientific inquiry as I was taught in my Master’s program. While I did find valuable resources such as ExploreLearning and SpaceClass, in addition to inexpensive physical experiments, it was hard to justify to the administration why I was not using the purchased curriculum. This frustration with using prestructured curricula that did not have the design components I wanted led me to think about teaching more as design and less as instructing students.

Although I did work at a hybrid charter school, this school is not part of the population for this study and I have no personal connection to any of the cyber charter schools that agreed to participate in the study. I have had other opportunities to see that the media used in learning is not as important of a factor in learning outcomes (Clark, 1983), as is the design of the learning. I have also seen that technology is rapidly changing to improve upon currently existing products. The labs used in this study do not necessarily represent best practices in virtual labs but they do represent the labs that students are currently using.

The frustration of teaching in an online environment in which I felt hampered by misunderstandings of what represents quality instructional design for students led me to apply to the Ph.D. program at Penn State in Learning, Design, and Technology (formerly Instructional Systems). I was particularly fascinated by Dr. Carr-Chellman’s interest in cyber charter schools, and this has remained a research interest of mine throughout multiple classes and research projects. As constructivism has been emphasized a theoretical lens through which to build epistemological beliefs, it has factored heavily in my model of what an ideal scientific practices based lab should encapsulate.
Chapter 4

Results

This chapter includes the results and analysis of the data collected. The chapter is organized with a description of each of the cyber charter schools that participated in the research, contextualization of the laboratory experience through interviews with a teacher from each cyber charter school, and then the presentation of the findings from the directed, ECA of the labs that students are using. These results are organized by research question. The unit of analysis is the theme(s) that emerge related to the content of the content analysis. These themes are categorized in steps 12-14 of the ethnographic content analysis seen in Table 3.2. The final measure of analysis is concise case studies summarizing the content found in each lab (or group of labs) and how they relate to the framework formed as a composite of all of the labs analyzed. A numerical analysis consistent with ECA is included to summarize the findings and provide a focused transition into the discussion of the results.

Description of Each Cyber Charter School

The following section includes a description of each cyber charter school that agreed to participate in the research. In the interest of preserving the confidentiality of participants their real names will not be used and any identifying features of the schools will not be included. The schools will be described according to their student enrollment, the time that they were chartered, any learning supports that are present for the students, and their curriculum as described on their Web site. The student enrollment for the cyber charter schools is classified according to size. A cyber charter school between 1-200 students is ‘small’, 200-2,000 students is ‘medium’, and 2,000-10,000 is ‘large’. There is a risk of loss of confidentiality with including these descriptors
in the study but they are important for context because each cyber charter school is different. However, no identifiable student data are included in the description of these schools. A range of sizes was used, rather than exact population, to try and preserve the confidentiality of the schools.

**Cyber charter school A.** The first cyber charter school that is participating in this study recently celebrated their tenth year as a cyber charter school. In the 2011-2012 school year the school did not make adequate yearly progress (AYP) in academic performance or graduation rates but met AYP in participation rates. In addition in the 2013-2014 school year the school did not meet the SPP score of 70 which shows a school is on the path of success (Sludden & Westmaas, 2014). The school has a ‘large’ enrollment (Jack et al., 2013). The school has their main office located in central Pennsylvania. They are run by a nonprofit corporation that has in the past had a contract with a for-profit company to provide their curriculum. It was discovered through a conversation with an external colleague attending a webinar and through my interview with the teacher that there will be a new curriculum in place for the 2016-2017 school year and it will not be provided by a for-profit company. They are a K-12 cyber charter school and require all students to have a ‘learning coach’ who supports the student in their learning. The school emphasizes a personalized learning experience for students as well as providing students with a sense of community and support. This community is fostered through case examples of other students who attend, an emphasis of the importance of a learning coach, and connecting them to the broader virtual community. They are on a variety of social media sites. The school has ‘drop-in’ learning centers in select larger cities in Pennsylvania. Students may go there to complete their schoolwork but transportation is not provided to those sites. For students who do not have
access to these sites, either because of lack of transportation or geographical distance, there is a virtual learning center for them to receive assistance with their schoolwork.

**Cyber charter school B.** The second cyber charter school included in this study is also a K-12 cyber charter school. The school did not make AYP in the 2011-2012 school year in academic performance but did in participation and graduation rates. In addition this school did not meet the minimum SPP score of 70 that shows a path of school success (Sludden & Westmaas, 2014). The school is considered a ‘small’ cyber charter school (Jack et al., 2013). The main office for the school is located in eastern Pennsylvania. Their Web site is easily divided into resources for students at the elementary level, middle school level, and high school level. This cyber charter school is part of a larger community that includes brick-and-mortar K-12 schools and a college granting associate’s degrees intended to support and equip local communities with improving their own community. The cyber charter school was created after the organization realized that more flexibility was needed to reach students where they are. This school does not contract with or use specific curriculum providers for the students. When browsing their Web site certain pages or features are not fully finished. The page loads and has a navigation bar but has no content on the page.

**Cyber charter school C.** The third cyber charter school included in this study serves students from middle to secondary school. This school did not meet AYP for graduation or academic performance but did for test participation. In addition this school did not meet the minimum SPP score of 70 that shows the path of school success. This school can be considered a ‘medium’ cyber charter school (Jack et al., 2013). During phone conversations establishing the research partnership at this school, the CEO of the school changed. The main office for this school is located in eastern Pennsylvania. The main page of the school Web site emphasizes the
facts that they have accredited curriculum and give students personalization in their learning. They indicate that their students come from all over the state and all have different needs in their learning. The Web site features students who express the positives of being able to have a flexible educational environment. Students who have the ability to visit a learning center are able to visit the main center or one of two satellite learning centers. The Web site features both a section for students to see what would be expected of them over the course of the day as well as a quiz to see if cyber charter school education would be right for them.

**Cyber charter school D.** The fourth cyber charter school that participated in this study is located in western Pennsylvania serving K-12 students. This school successfully made AYP for graduation, academic performance, and test participation in the 2011-2013 school year. The school especially excelled at the middle school level in academic performance. This school is at the lower end of a large cyber charter school (Jack et al., 2013). This school did not reach the minimum score of 70 on the SPP that shows a path of school success, but was one of the highest achieving cyber charter schools and close to this number. The school has several drop-in centers throughout the state for students who need more structure and assistance in their learning. This school has stable leadership as the founder of the school is still its CEO. This school emphasizes personalized instruction through the support of an at-home learning facilitator. The mission of the school stresses that they will mentor students and provide them with global perspectives on the world. The school had eighteen 2015 national merit semifinalists. In the description for their seventh grade science course students are expected to design and conduct investigations. The Web site has sections for students, parents, and teachers.

**Cyber charter school E.** The final cyber charter school that participated in this study is located in central Pennsylvania serving K-12 students. Their AYP information is not available
from the Pennsylvania Department of Education Academic Achievement Report. The school is considered a small cyber charter school (Jack et al., 2013). This school did not meet the minimum SPP score of 70 and was in the lowest tier of cyber charter schools reporting SPP scores (Jack et al., 2013). This school primarily draws from local counties and there are rotating learning labs that students can go to for extra support as well as weekly office hours. The school’s Web site looks unfinished and does not provide much detail on the academic experiences students will have or how to be successful in a cyber charter school. The school emphasizes a small community atmosphere, high quality teachers, and the computer/internet resources needed for students to be successful in their schoolwork. The Web site is not divided into separate sections for students, teachers, and parents.

**Contextualization of ‘Laboratory’ Experience through Teacher Interviews**

From interviews with teachers, certain themes appeared when discussing courses and labs that students complete. These themes make it easier to understand the variation in the labs and amount of support students receive when completing labs; as well as expectations for students, communication strategies, and the differing concepts of the word “lab” in a virtual environment. These themes were created using thematic analysis (Braun & Clarke, 2006). The thematic maps created during the course of analysis can be seen in Appendix E.

The analysis process for the teacher interviews was done without a CAQDAS program because of the small sample size. Four of the school interviews were conducted with one teacher. This was because only one teacher taught the course (Cyber Charter School E and Cyber Charter School B), because the school had a purchased curriculum so every class was the same (Cyber Charter School A), or each teacher taught their class independently (Cyber Charter School D). One of the interviews was conducted with three teachers at one school as they work closely
together to develop the curriculum for the students (Cyber Charter School C). The interviews with Cyber Charter School E, Cyber Charter School B, and Cyber Charter School C were conducted within Penn State’s Adobe Connect videoconference system. The interview with Cyber Charter School A was in their Adobe Connect room and the interview with Cyber Charter School D was in the teacher’s Zoom room. Table 4.1 identifies the school pseudonym, what course the teacher(s) taught, the LMS used, how many teachers teach the course, the content typical covered, any virtual software used for labs, the delivery of the class, and if there are physical support centers for the students.

Table 4.1

<table>
<thead>
<tr>
<th>School Name</th>
<th>Course They Teach</th>
<th>LMS Used</th>
<th>Number of teachers</th>
<th>Content Covered in the Course</th>
<th>Purchased or Local</th>
<th>Virtual Software Used in Labs</th>
<th>Class Structure</th>
<th>Drop-In or Learning Support Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyber Charter School A</td>
<td>7th grade science A and B</td>
<td>Connexus</td>
<td>6</td>
<td>Chemistry, Biology , Earth Science</td>
<td>Purchased</td>
<td>PhET</td>
<td>Live Lessons</td>
<td>Drop-in centers, located in Harrisburg and Philadelphia</td>
</tr>
<tr>
<td>Cyber Charter School B</td>
<td>Life Science</td>
<td>N/A</td>
<td>1</td>
<td>Biology</td>
<td>Local Design</td>
<td>A variety of free and open resources</td>
<td>Daily Synchronous Session</td>
<td>Part of larger community created primarily for Latino community near Philadelphia</td>
</tr>
<tr>
<td>Cyber Charter School C</td>
<td>General Science</td>
<td>Moodle</td>
<td>3</td>
<td>Local Design, Subscription and free</td>
<td>Gizmos (ExploreLearning), PhET, BrainPop, Prentice Hall Active Arts</td>
<td>Live Classes Monday - Thursday</td>
<td>No drop-in centers, dissolved at the end of the 2014 school year</td>
<td></td>
</tr>
<tr>
<td>Cyber Charter School D</td>
<td>Life Science</td>
<td>Moodle</td>
<td>2</td>
<td>Life Science</td>
<td>Local Design</td>
<td>A variety of free and</td>
<td>All asynchronous</td>
<td>No drop-in centers,</td>
</tr>
</tbody>
</table>
The teacher interviews revealed (a) general patterns of student completion of labs; (b) how frequently they complete labs and; (c) the favorite labs of teachers. All of the teachers spoke of their favorite labs based on how they felt students enjoyed the labs and the extent to which the labs were successful in that the procedures produced the intended result. The quote from Cyber Charter School A illustrates this.

**Cyber charter school A:** So I like this one because it creates an endothermic reaction and they [students] can feel that bag getting cold. So a lot of kids will think when you mix that baking soda with that vinegar it will get hot and bubble so it does bubble but it gets cold so that is maybe not what they think so it is interesting to see their results when it gets cold.

The teachers who are employed at Cyber Charter School’s C, B, and D also select labs based on their ability to effectively deliver inquiry for students.

**Cyber charter school B:** I feel like it is more challenging in the virtual environment to get them to that inquiry part but I feel like especially with the dissections and things that they get to do it kind of encourages more ok so this is my hypothesis I described it and it
 didn’t work I need to go back and do more research…so I feel like those are more hands-on and the ones where inquiry happens.

Table 4.2 shows what labs are assigned to the students, how frequently they do the labs, and what the favorite labs of the teachers are.

Table 4.2

*The School, Lab Choice, and Lab Frequency*

<table>
<thead>
<tr>
<th>School</th>
<th>Type of Labs</th>
<th>Frequency of Hands-On Labs</th>
<th>Frequency of Virtual Labs</th>
<th>Favorite Labs of Teacher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyber charter school A</td>
<td>Mostly virtual labs, a few physical labs</td>
<td>Half</td>
<td>Half</td>
<td>mass movement, Exothermic and endothermic</td>
</tr>
<tr>
<td>Cyber charter school B</td>
<td>All Virtual</td>
<td>Never</td>
<td>All, Fall in the second half of the semester</td>
<td>Virtual dissectios</td>
</tr>
<tr>
<td>Cyber charter school C</td>
<td>Mostly virtual, a few whole school physical labs</td>
<td>Few over the course of the school year</td>
<td>Once a pod, A pod is three weeks, at least 9 total</td>
<td>Vector drawing, molecular movement</td>
</tr>
<tr>
<td>Cyber charter school D</td>
<td>All virtual</td>
<td>Never</td>
<td>1-2 per marking period</td>
<td>Microscope lab, gummy bear osmosis lab</td>
</tr>
<tr>
<td>Cyber charter school E</td>
<td>Hands-on with common household materials, a few virtual labs</td>
<td>Mostly</td>
<td>Rarely</td>
<td>Volcano, sorting and identifying fossils, rock lab, virtual</td>
</tr>
</tbody>
</table>
Themes from the Thematic Analysis of Teacher Interviews

As a result of the thematic analysis detailed by Braun and Clarke (2006) eight themes were identified from the teacher interviews. These interviews help to contextualize the similarities and differences between how the five cyber charter schools in this study use science labs in their middle school science classes. The themes are (1) the design of the labs; (2) teacher dedication and improvisation; (3) teacher availability to students; (4) communication practices; (5) parental expectations from the school; (6) challenges with the virtual labs; (7) willingness to allow revisions and give detailed feedback to students; and (8) teacher definitions of labs in the virtual setting.

Theme 1: Design of the labs. Depending on the curriculum and pedagogical decisions of the cyber charter school leadership, the teachers interviewed had one of three options for the design of science labs for students. The first option was that the school purchased a prescribed curriculum and the teachers were unable to, or did not see a need to deviate from this curriculum. Cyber Charter School A was unable to deviate from the curriculum and this was frustrating for the teacher.

Cyber charter school A: I cannot change the actual document the way that they have to do it… I can’t change things in the software program that is the way it is. That is something that we want to have more autonomy with because we are not fans with a lot of these things as teachers because we don’t have to say in it.

At Cyber Charter School E the teacher was able to change the curriculum but did not see an issue with the way it was designed for students.
Cyber charter school E: No they are part of the course. We can, we certainly can but I have found that the ones that are within the courses are perfectly fine and I haven’t done that.

The second option was that the teachers were encouraged to use open resources while the school maintained software subscriptions inconsistently. Teachers became discouraged from developing content around the purchased software because it would not always be available and the significant time it takes to develop labs could be lost if the subscription was not renewed.

Cyber charter school C, Teacher 1: It takes a lot of time to create these items and that is not the amount of time that we have on a regular basis as for what is free and paid we had other paid things like science specific things that did not get renewed so I know they used Gizmos before I worked here and we no longer pay for that.

The third option was that the school did not provide any purchased software/curricula and the teachers were expected to find resources on their own.

Cyber charter school B: My entire curriculum I built in to align to the eligible content on the Keystones but outside of that I have autonomy in what I do.

The teachers who worked for schools with the second or third options invested significant time and resources to contextualize the labs, and provide students with an experience rooted in inquiry or nature of science concepts.

Cyber charter school B: Most of the Web sites have feedback that goes with it they may have questions but I never use those I make my own

Cyber charter school D: I try not to give chapter tests when I don’t have to so this is like a culminating activity of everything we have covered in their nature of science unit so going through variables and telling me what they are going to adjust and why they are
going to adjust it so justifying your answer, qualitative or quantitative data and they can
type directly into their worksheet.

**Cyber charter school C, Teacher 2:** And I have done virtual field trips where I have
gone to a site and performed a field trip and brought back the data and pictures to create a
lesson for the kids.

When the teachers have created their own labs they take ownership of that creation. This
leads Jim to feeling that the students also take more ownership of their learning that way.

**Cyber charter school C, Teacher 2:** In my mind I created that even though it was a
simulation from PhET the actual assignment and the questions and the data table you
know what I am saying I don’t know to me that was teacher created even though we are
using a simulation of someone else.

**Cyber charter school C, Teacher 2:** This is actual data I collected for them to use…so I
showed them pictures of soil erosion and showed them pictures of the pavement…I feel
like if they see me doing it they take more ownership than if I show them a YouTube
with some stranger.

This is an important point because being proud of and taking ownership in the curriculum
provides an outlet for teacher voice and allows the teachers to feel passionate about and valued in
their work (Sutherland, Howard, & Markauskaite, 2010).

**Theme 2: Teacher dedication and improvisation.** The second theme threaded through
all of the interviews regardless of lab design. All of the teachers were emphatic in being
dedicated to their students and improvising to serve students at their point of need. The teachers
scaffold and create iterative cycles of support for students. This is seen when Cyber Charter
School D is discussing how many students write their lab reports unassisted.
**Cyber charter school D:** They would say the experiment worked and that is all they would say. Well that is not a proper conclusion so obviously I have to help them write a conclusion so I literally do it step-by-step. So in sentence one what was our class hypothesis and this whole thing was about a controlled experiment so then in sentence two all in cohesive paragraphs don’t just write yes or no but write whether the hypothesis was confirmed or rejected and it was all written out for a total of seven sentences. So I tell them use the prompts to write a cohesive paragraph.

**Cyber charter school B:** Pretty much they pick it up pretty quickly but for the more in-depth labs like the dissection lab I will make a snapshot instruction sheet specifically for the special education kids because they can get a little lost when they are given too many steps so I break it up for them.

The teacher from Cyber Charter School A felt limited by the purchased software emphasizes to students what he actually expects of them and improvises on the curriculum as it is presented.

**Cyber charter school A:** And again this is something for seventh grade and I don’t want everybody getting poor grades on the portfolio and there are not enough students who do it the right way so I just say listen you can do it in paragraphs.

Cyber Charter Schools A and E use some physical labs where students complete the labs using household materials. However, these materials are not always available to the students and the teachers will adapt the lesson so that the students can successfully complete the lab.

**Cyber charter school A:** Some of the kids say they don’t have baking soda or whatever any of the potential reactant and if they don’t and I believe it is legit I will say look just watch my video, watch my experiment, and write your procedures on what I have done.
**Cyber charter school E:** What we try to do is recommend replacements…lots of things like that (replacing metal shavings in one of the experiments) that we just make appropriate replacements.

The teachers want to do more but feel limited by time and other external factors that prevent them from doing as much with their middle school science courses as they want.

**Cyber charter school D:** I would say yes but unfortunately I can’t do what I want to do because I just don’t have the time and I am teaching three other classes as well.

**Cyber charter school C, Teacher 1:** It takes a lot of time to create these items and that is not the amount of time that we have on a regular basis.

A concerning problem that threaded through all of the interviews is that the teachers make themselves available to students to help and guide them, but not enough students reach out to the teachers for help.

**Cyber charter school C, Teacher 2:** We are trying different and unique ways to get them more engaged within the cafes because the cafes are new this year for our school so it is kind of like a work in progress where we are finding the best motivators to get them to come in.

**Cyber charter school B:** So the kids that are really dedicated will reach out a lot of times they will send me emails or again go on to Blackboard and send me a message through there. There have been a few kids because I also have a school cell phone that will send me a picture message.

Volery and Lord (2000) identify that one of the critical factors for success in online education is the teacher reaching out to prevent the feeling of isolation for students and having many ways to communicate to students. Students’ perceive one of the challenges of online
learning to be feeling connected and having a relationship with their instructor (Song, Singleton, Hill, & Hwa Koh, 2004). However, the reasons for why students do not reach out to their instructors when the instructors do make themselves readily available are not apparent from the existing literature and are important when considering how vital communication is to being successful in science (Hoadley, 2000).

**Theme 3: Availability to students.** There are multiple delivery mechanisms that the schools can choose to use for their courses. Cyber Charter Schools A, B, and D offer synchronous classes and live lessons while cyber charter school C offers once a semester collaboration sessions with the rest of the class being asynchronous while cyber charter school D has all asynchronous classes at the middle school level and limited synchronous classes at the high school level to those that are assessed by standardized tests. This delivery mechanism, as well as the LMS used, affects how teachers make themselves available to students. It does not, however, impact the effort that teachers make to be available for their students. There are variations in how often the teachers are available and how they expect student communication to work. While the first two teachers quoted expect students to reach out to them when they are having difficulty, the other three schools take a more proactive approach and communicate with students in advance of and during times the students are struggling or have questions.

**Cyber charter school E:** Office hours once a week…they will also email me and I will call them back…and we have got Skype for chat.

**Cyber charter school B:** So the kids that are really dedicated will reach out to a lot of times they will send me emails or again go on Blackboard and send me a message through there. There have been a few kids because I also have a school cell phone that will send me a picture message.
**Cyber charter school A:** What I do for my students is I give them my cell phone number if it is office hours or school hours call me on my office phone but if you have a question at 8 at night or 10 in the morning on Saturday or Sunday give me a call. So I personally try to make myself available to them and I learned that because this is a second career…get my teaching certificate from Drexel at night my teachers made themselves available to me on the weekends and for them to just make themselves available to me and allow me to call them on the weekends I just really appreciated that so I started doing that on the weekends and not enough students take advantage of that.

**Cyber charter school D:** They know they can get ahold of me between the hours of 7-3 so obviously if I don’t get the message until 2:45 I am probably not going to help them that day and I have turned students away and said okay it is almost 3 o clock and I need to leave so if you have a quick question I will be happy to answer it but otherwise come and see me tomorrow just so I can make more time for your needs. I do night hours as well so they know that they can come and see me at night.

**Cyber charter school C, Teacher 3:** Cybercafes are open all day 8 AM – 8 PM and on Friday from 10-2 they can email us, they can call us, they can text us.

An interesting finding that deserves further attention is the unequal distribution of physical learning centers for students. Three of the five cyber charter schools have some form of a physical drop-in center while cyber charter school D used to have drop-in centers but faced pressure to shut them down.

**Cyber charter school C, Teacher 1:** That is something that we used in the past but at the end of this past school year they closed down our centers out of concern…there was a cease-
and-desist letter that came from the state…and I think that along with financial concerns is the reason we closed our centers.

Students are responsible for securing the transportation to go to the drop-in centers and not all students live within geographic proximity to a physical drop-in center. This can lead to an unequal distribution of resources unless there is an equivalent virtual center for students to go and get the support they need. It was clear that the physical drop-in centers were one of the only ways that students communicated with one another while completing the labs. The teachers were not clear why the cease-and-desist order came from the state.

**Cyber charter school A:** But in terms of interacting with one another while they are doing the labs…not really…unless they go to one of the drop-in centers because the CCA assistant teacher is probably not working one on one he is probably working with a small group.

**Theme 4: Communication practices with science labs.** Communication is essential for students participating and transitioning their scientific thinking when engaged with the labs. Quinn et al., (2012) emphasize this importance of communicating while students are building their science thinking. Unfortunately the level of communication tends to be lackluster among students, their peers, and their teachers.

**Cyber charter school D:** No that is where our system is kind of lacking. We do have a function called forum where they can connect and talk virtually. I also have something we did as a class so they can never video talk to each other without a teacher’s supervision so they can come to class chat and we actually have class chat every week….so here is something to try and get them to communicate with each other…we
looked at different traits…each student put here what they had so they are talking to each other a little bit (on the forum).

**Cyber charter school C, Teacher 2:** It depends, sometimes it happens and sometimes it doesn’t. Like I said that would be an ideal situation but sometimes it is more difficult to get to every single one of them on every single lab.

The only true discussion that happens across all of the cyber charter schools are those that talk about the labs during their live and synchronous sessions.

**Cyber charter school C, Teacher 1:** We give them mic privileges and Jim: We put them in breakout rooms. Rachel: We kind of give them a lot of guided instruction. We model it first and then we have them practice in small groups. And sometimes if we are lucky we will have a really strong student who will help other students so we will ask them online if they would be interested in working with someone else.

**Cyber charter school A:** When we do the live lesson that you can see here where you types in this chat box is usually real active all lesson long and you have to watch because sometimes the comments are more related to Minecraft than to school so I have to filter those but when we are in live lesson they will interact and we will talk you know what happened, how did your thermometer work?

Schools that have discussion boards do not see active engagement on them.

**VR:** Okay and do you find those are active, the discussion boards?

**Cyber charter school B:** Not really, they prefer just to talk about it in class.

Finally, it was seen that communication was improved if the class happened to have a student leader that helped to organize and lead student engagement. It is important for cyber
charter schools to explore further how they can capitalize on this notion of a student leader to
improve communication, engagement, and belonging for students.

**Cyber charter school E:** It usually takes a student who is kind of a leader anyway…and
being there to encourage their peers.

The absence of a scaled and intentional effort to foster communication collaboration in
the virtual labs is concerning due to the importance that has been placed on collaboration in
helping students learn (Rummel & Spada, 2005).

**Theme 5: Parental expectations from school.** Parental or guardian involvement in their
student’s education at cyber charter schools, especially below the high school level, are
important to provide support for students to succeed. When thinking about science labs, the
parents could play a role in helping to foster student thinking or make meaning from the labs at
home. However it is clear that the relationship between the parents and the schools can be
improved.

**Cyber charter school E:** I think a lot of the courses that we deal with are almost afraid
to ask that to happen because very often there is nobody there that is going to help them.

**Cyber charter school D:** I really haven’t found a good way (to get parents involved).
Either a parent is going to be involved or not going to be involved and maybe it is just the
type of student I am dealing with but they are not involved period.

**Cyber charter school E:** I found a volcano experiment where they have to build their
own volcano there and that certainly goes a lot better when they have a parent or guardian
helping them.
Cyber charter school A: With our school here we have our students and the student usually works from home with what they call a learning coach. There is somebody who is assigned as the learning coach and they are to work through with the student. Now depending on the situation sometimes that might happen…but there are a lot of kids kind of working on their own as well because mom is working and dad is nowhere to be found.

Huerta, Gonzalez, and d’Entremont (2006) consider parental involvement from the policy perspective in cyber charter schools, but the role of the parent in science learning in an online environment is unknown.

Theme 6: Challenges with labs in a cyber charter school. All of the teachers experienced challenges in creating successful lab experiences for their students. Some of these challenges are associated with student characteristics and their current ability. It is clear that more direction needs to be given to students to successfully navigate the online learning environment and know how to manage their coursework. While not a discovery-based learning environment (Mayer, 2004) the characteristics that cause these environments to fail in instruction can be applied to cyber charter schools.

Cyber charter school E: Probably just the fact that they really don’t want to do it either they are way behind…or they are zooming ahead. I think they want to move through multiple choice and true/false questions and don’t want to put the time into it.

Cyber charter school A: We have found out as a team of teachers that the kids, especially the low functioning kids they get real excited when we have a portfolio and there will be 10% of the kids as we get to a portfolio (lab) as they are working through and they will stop and they won’t do science for 3-4 weeks because of that and when you
have 140 kids sometimes you won’t pick up on that until 2 weeks out and then they get behind quite a way.

The idea that there needs to be a clearer way of supporting students can be seen from the teacher at Cyber Charter School A.

**Cyber charter school A:** Sometimes I think the directions are not the clearest.

**Cyber charter school A:** For the new and sincere families who are really trying to learn they can become overwhelmed rather quickly so I always want to make sure they don’t become overwhelmed.

Another challenge of the labs has to do with learning in the online environment. The teachers felt like engaging different levels of students with the nature of science in an online environment is hard and they do not know how to assess their effort in engaging students.

**Cyber charter school B:** I feel like it is more challenging in the virtual environment to get them to that inquiry part but I feel like especially with the dissections and things that they get to do it kind of encourages more ok this is my hypothesis I described it and it didn’t work I need to go back and do more research…so I feel like those are more hands-on and the ones where inquiry happens.

**Cyber charter school C, Teacher 2:** One of the battles that all of us have is making sure the kids are doing their work and that is the case in any cyber charter that you will go to. We have different reading levels, different SES, so it is a battle to get them to do everything.

**Cyber charter school D:** I don’t know if the kid understood the concept and I think that is where the whole lapse with cyber charter school.
Theme 7: Teacher willingness to allow revisions and give feedback. A remarkable strength of the teachers’ role in cyber charter schools is the willingness to allow revisions and in turn create a mastery-based learning environment (Block & Burns, 1976). Similar to how students are allowed to fail in environments like video games (Gee, 2007) or competency-based learning (Voorhees, 2001), all of the teachers allow for revisions for students until they earn a more desirable number of points. The design of some of the virtual labs also create a mastery-based learning environment that allow for students to experiment and try many different processes while they are doing a lab.

Cyber charter school E: I go over it (the lab report) and give them lots of input…I don’t even make a penalty in terms of doing it a second time.

Cyber charter school D: Definitely with this population I give them the chance to go back through and make corrections now whether they do that…

Cyber charter school A: By communicating, by allowing them to redo assessments when they make mistakes.

Giving prompt, constructive feedback to students is important because it allows them to see where they could improve, creates a personal relationship with their teacher, and makes students feel like they are a valued part of the class. All of the teachers use their LMS to provide students with feedback. The feedback is personalized and very responsive to the student work.

Cyber charter school C, Teacher 2: They get immediate feedback. I try to grade things daily so they get the immediate feedback that way they have the ability to revise their work and turn it back in.

Cyber charter school B: When they submit it on Blackboard to be graded it will come up and the program Blackboard uses to grade gives me an option to give comments and
grade so for specific students I will give them their feedback there and then if it is something that occurred over all of them or most of them we will go over feedback in class as well.

**Theme 8: Teacher defining of science labs in an online environment.** The most unexpected finding from communicating with multiple cyber charter schools and interviewing the teachers was the variation in how teachers define and students experience science labs in the online setting. The accepted definition of science labs from the *NRC Framework* is not always consistent with how students in cyber charter schools conduct labs. The definition is “laboratory experiences provide opportunities for students to interact directly with the material world (or with data drawn from the material world), using the tools, data collection techniques, models, and theories of science.” (Singer, Hilton, & Schweingruber, 2005, p. 3).

The definition of a virtual lab from Chen (2010) is ambiguous in its understanding of what students actually do in the labs and focuses more on the design of the labs emphasizing learning content and less on actually designing and conducting experiments. The teachers referenced either the scientific method or the nature of science when defining labs.

**Cyber charter school D:** So for me a lab is anything that applies the scientific method so going through maybe just any one of the inferring, classifying, making observations, anything that deals with the nature of science is for me a lab.

**Cyber charter school C, Teacher 3:** Alright so for me I try and stick with the scientific inquiry method not necessarily in the formalized sense but as you noticed when teacher 2 was showing you the example, they are collecting data, they are thinking, so for me that is basically my outline and then I work into that like keeping it similar through all things.
The teachers were very insistent on what could not be truly considered a virtual lab and this focuses on how much responsibility the students have for experimenting and the ability to promote critical thinking. However, some teachers were extremely limited by their curricula in creating labs how they would like to.

**Cyber charter school A:** When I think of a lab a lot of these they are not really labs they get some information together…but I would like to see more experimentation which I don’t know how you would do that…I am sure there is some program where there is an online thing where you can do an online experiment but I never really thought much about it because this is the curriculum and this is what we teacher and this is what we do but if we are given that freedom going forward maybe that will change and the team of teachers will put our minds together in terms of experimentation rather than just putting facts on paper.

**Cyber charter school B:** The only ones (labs) that I have that I dislike using they call them web quests and they call them labs but really they just make the students do a round of research with small activities they don’t really make them think at all.

The final way that the teachers thought about virtual labs was in their level of interactivity. As long as a student was actively engaged with the screen and clicking to make things happen then it was considered a lab.

**Cyber charter school C, Teacher 2:** If it is an interactive experiences for the student that in my mind constitutes a lab even though you don’t have a beaker in front of you.

**Cyber charter school E:** An experiment is an activity where we are testing a hypothesis. To me some sites have a particular virtual lab and within the whole laboratory are experiments and the experiment is where we actually do the work.
Interestingly, none of the teachers discussed the content when talking about what a virtual lab is. This is different from existing research that focuses heavily on the content of the labs (Chen, 2010) or measures what content students learned from the labs (Pyatt & Sims, 2011). The teachers were originally asked to identify labs they thought would be good to analyze but this did not happen because the teachers were not familiar with the NGSS and the labs were not restricted to life science concepts. The labs were identified from going through the curriculum, identifying core ideas the students were exposed to, and focusing on if they had inquiry, interactivity, and critical thinking in the labs as this is what the teachers emphasized in their labs.

**Findings from Directed, Ethnographic Content Analysis**

The core of this study, identifying potential markers of engaging students with science practices and crosscutting concepts, relied on a content analysis of the labs students would complete. Each school had a different way for me to access the data and this is described first. The structure for the results follows Table 4.3 that identifies the labs selected from each school, a matrix showing what each lab had in them based on the existing and emergent categories from the ECA steps in Tables 4.6 and 4.7, and a further description of each section of categories. A case description summarizing the labs from each school completes step 15 of the ECA and the numerical presentation of the narrative completes the analysis according to ECA (Altheide, 1987; Krippendorf, 2012).

**Accessing of curricula.** Cyber Charter Schools B and E were open to giving access to the virtual labs used and worked quickly to provide access. The teacher at Cyber Charter School B provided a list of labs and supporting documents she uses throughout the school year. Cyber Charter School E worked with their technical department to create a student demo account to log-in and explore comprehensive science 7.
Cyber Charter School A required FERPA agreements and then created a student account for me to access the course. Cyber Charter School D allowed views of the curriculum through the teacher’s Zoom room. Times were set to access the virtual labs while the teacher controlled the room. Screenshots were taken along with quick analysis to further analyze the labs. The URL’s were provided for open resources so that they could be accessed after the meeting with the teacher. Cyber Charter School C was initially very resistant to an outside researcher having access to the curriculum. To gain access the school created a dummy account in their LMS and the three teachers interviewed added all of their virtual lab materials into this dummy page for analysis.

Labs selected. The labs selected from each cyber charter school are outlined in table 5 below. The labs were selected based on initial impressions of their relevance to life science, the teachers focus of labs being related to the scientific method and interactive experiences, and finally on non-subject related labs that met the teacher description of their labs. The teachers were not sufficiently familiar with the NGSS to choose labs under various standards. The content in the lab was used to match it to a NGSS standard and core idea. The labs did not necessarily meet all components of that standard, but were related to that disciplinary core idea. Table 4.3 shows the labs selected and the NGSS core idea met by each lab.

<table>
<thead>
<tr>
<th>Labs Selected by Cyber Charter School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyber Charter Schools</td>
</tr>
<tr>
<td>A B C D E Labs Studied</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>Core Idea</strong></td>
</tr>
<tr>
<td><strong>NGSS Standard</strong></td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td><strong>Core Idea</strong></td>
</tr>
<tr>
<td><strong>NGSS Standard Addressed</strong></td>
</tr>
</tbody>
</table>
at a distance
can be different
amounts of potential energy
are stored in the system

<table>
<thead>
<tr>
<th>3</th>
<th>Directed Virtual Lab: Mendel’s Experiments 101</th>
<th>Virtual Frog Dissection</th>
<th>Matter Changing States</th>
<th>Naked egg osmosis lab</th>
<th>Tulips: Controlling Variables (1.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Idea</td>
<td>Heredity: Inheritance and variation of traits</td>
<td>Biological evolution: Unity and diversity</td>
<td>Matter and Its Interactions</td>
<td>From molecules to organisms: Structures and processes</td>
<td>From molecules to organisms: Structures and processes</td>
</tr>
<tr>
<td>NGSS Standard Addressed</td>
<td>MS-LS3-2. Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation</td>
<td>MS-LS4-2. Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships</td>
<td>MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed</td>
<td>MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.</td>
<td>MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organism.</td>
</tr>
<tr>
<td>4</td>
<td>Mouse genetics (one trait) (ExploreLearning)</td>
<td>PhET Natural Selection (Uses multiple PhET labs)</td>
<td>Will it Fossilize Lab?</td>
<td>Gummy bear osmosis and diffusion lab</td>
<td>Graphing and Predicting Earthquakes (3.07)</td>
</tr>
<tr>
<td>Core Idea</td>
<td>Heredity: Inheritance and variation of traits</td>
<td>Biological evolution: Unity and diversity</td>
<td>Biological evolution: Unity and diversity</td>
<td>From molecules to organisms: Structures and processes</td>
<td>Earth and human activity</td>
</tr>
<tr>
<td></td>
<td>MS-LS3-2. Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation</td>
<td>MS-LS4-4. Construct an explanation</td>
<td>MS-LS4-1. Analyze and interpret data for</td>
<td>MS-LS1-3. Use argument supported by</td>
<td>MS-ESS3-2. Analyze and interpret data on</td>
</tr>
<tr>
<td>NGSS Standard Addressed</td>
<td>Reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation</td>
<td>based on evidence that described how genetic variations of traits in a population increase some individuals’ probability of surviving and reproducing in a specific environment</td>
<td>patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past</td>
<td>evidence for how the body is a system of interacting subsystems composed of groups of cells</td>
<td>natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.</td>
</tr>
</tbody>
</table>

*Note.* Standards and core ideas are taken from the NGSS standards found at [http://www.nextgenscience.org/get-to-know](http://www.nextgenscience.org/get-to-know)

**Description of Lab Selection.** Cyber Charter School A required FERPA regulation forms to be signed and then I was given access to the curriculum as a volunteer tutor. The labs were accessed through the home page which went to all of their lessons for 7th grade science. There are four units in 7th grade science: energy, waves and electromagnetic radiation, introduction to genetics, and natural selection and adaptation. Discussion boards with student information or vendors that required additional access such as Discovery Education were not accessible.

Cyber Charter School B provided an excel sheet of the labs the teacher used. There were 10 labs on this sheet and four labs were selected based on having them be from different websites and were explicitly titled labs in the excel sheet. The labs identified were the blood typing, pH testing, frog dissection, and natural selection. It should be noted that one of the labs listed is the microscope lab that cyber charter school D also used.

Cyber Charter School C was resistant to granting access to the labs. Multiple administrators were contacted to attempt to gain access to the labs. The solution was for the teachers interviews to upload their labs to a demo account. There were a total of fifteen labs uploaded into the demo account.
Cyber Charter School D allowed access to their labs through a teacher Zoom room. The teacher opened their course in a synchronous session and controlled the access to the labs. I selected labs to analyze and the teacher would scroll through the lab under my prompted direction. I took screenshots of the labs and recorded the links to the open resources that she used. I took brief notes to orient the screenshots and the features of the lab and then used the screenshots, notes, and the open resources to analyze the labs after we met. The Zoom meeting took two hours to take the screenshots and describe them in enough detail to contextualize them for analysis. The students have completed fifteen virtual lab activities so far this school year. This is the first year that this teacher has taught the middle school science course and so the lab activities for the rest of the year have not been decided yet. The content ranges from introduction to science to life science to earth science to physical science and back to life science.

Cyber Charter School E has 6 units in comprehensive science 7. These are Science: The basics, energy, the earth and how it changes, how we are different and how we evolve as living things. The labs targeted for this curriculum analysis came from units 1, 5, and 6 as they are related to science inquiry concepts and life science. It was hard to identify what classified as a lab in the lessons as it was not specifically stated what a lab was and everything was called an assessment. After going through every lesson the students would complete the criteria to qualify as a lab for these students is the assessment had to have students actively interact with the page, make predictions/collect data/observe, conclude on their findings, and/or engage in a lesson that led to testable outcomes. This last criterion was hard to fulfill as many of the assessments fulfilled the other tasks but structured them as worksheets or individual activities rather than a lab.
Cumulative Presentation of Analysis

Using existing literature on science labs combined with emergent categories from the ECA a table was created to show all of the possible markers to engage students with science practices and crosscutting concepts that could be seen in the virtual science labs. The key for this lab is if it is a solid hexagon (●) for that marker it is present in the lab. If it is a half donut (●) then the lab partially has this marker. If the lab has an open circle (○) it is because that feature is present in the curriculum for the students but not specifically in the virtual lab software. The open circle (○) is not analyzed beyond Tables 4.4 and 4.5 because this curricula was not accessible from all of the schools nor was it part of the research questions. Table 4.4 presents the science practices and crosscutting concepts. Table 4.5 presents the constructivist design, part of the constructivist learning environments, and the emergent features not previously identified in the literature. The science practices were marked with a solid hexagon if the lab allowed for full control over using that science practice and a half donut if the lab took over some control of that practice. The crosscutting concepts were marked with a solid hexagon if the concept was made explicit in the lab and a half-donut if the concept was present in the lab but remained implicit.

The constructivist design features and constructivist learning environment were marked with a solid hexagon if the component was present throughout the lab and a half-donut if portions of the lab were designed for that features but others were not. For example, if the lab presented information through multiple perspectives in the introduction but not in the conclusion it was marked with a half-donut. For the emergent features they are all marked as present in the lab. These features were not identified in previous studies of virtual labs so marking them with a solid hexagon simply marks their presence in the lab.
These emergent categories emerge from my experience in online learning environments and mentioned in the literature as important for online learning but not for virtual science labs necessarily. For example, time is mentioned as a benefit of virtual labs, but it is not identified how it is determined if a lab clearly reduces time for students. If a lab has students do an experiment such as fruit fly breeding, but does not make it obvious through the simulation that the experiment is fast-forwarded then it would not be clear when completing the lab of how long it takes fruit flies to reproduce. Whereas, another lab using the same experiment could indicate that the time to complete the experiment is reduced. Table 4.4 presents analysis of the science practices and crosscutting concepts and Table 4.5 presents analysis of the constructivist design features, learning environment, and emergent features not previously identified.

Table 4.4

*The Science Practices and Crosscutting Concepts in Virtual Science Labs*

<table>
<thead>
<tr>
<th>Schools</th>
<th>Cyber Charter A</th>
<th>Cyber Charter B</th>
<th>Cyber Charter C</th>
<th>Cyber Charter D</th>
<th>Cyber Charter E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing (ex)</td>
<td>Lab A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>Identifiable Markers</td>
<td>Science Practices</td>
<td>Asking Questions</td>
<td>Developing and using models</td>
<td>Planning and carrying out investigations</td>
<td></td>
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<tr>
<td>Ex</td>
<td>☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒ ☒</td>
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<tr>
<td>Constructivist Design Features and Emergent Features in Labs</td>
<td>Cyber Charter A</td>
<td>Cyber Charter B</td>
<td>Cyber Charter C</td>
<td>Cyber Charter D</td>
<td>Cyber Charter E</td>
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<tr>
<td>Analyzing and interpreting data</td>
<td>⬤ ⬤ ⬤ ⬤ ⬤ ⬤</td>
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<tr>
<td>Using mathematics and computational thinking</td>
<td>⬤ ⬤ ⬤ ⬤ ⬤ ⬤</td>
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<tr>
<td>Constructing explanation</td>
<td>⬤ ⬤ ⬤ ⬤ ⬤ ⬤</td>
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<tr>
<td>Engaging in argument from evidence</td>
<td>⬤ ⬤ ⬤ ⬤ ⬤ ⬤</td>
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<tr>
<td>Obtaining, evaluating, and communicating information</td>
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</table>

Table 4.5

Constructivist Design Features and Emergent Features in Labs

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<thead>
<tr>
<th>Schools</th>
<th>Cyber Charter A</th>
<th>Cyber Charter B</th>
<th>Cyber Charter C</th>
<th>Cyber Charter D</th>
<th>Cyber Charter E</th>
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Table 4.5

Constructivist Design Features and Emergent Features in Labs

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<th>Cyber Charter C</th>
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Table 4.5

Constructivist Design Features and Emergent Features in Labs

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<th>Schools</th>
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<th>Cyber Charter B</th>
<th>Cyber Charter C</th>
<th>Cyber Charter D</th>
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</tbody>
</table>
### Supports from labs to help with markers

<table>
<thead>
<tr>
<th>Feature</th>
<th>Ex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication Features (peer-peer and peer-instructor)</td>
<td>O</td>
</tr>
<tr>
<td>Descriptive sequences</td>
<td></td>
</tr>
<tr>
<td>Scaffolds present (fading, channeling, modeling)</td>
<td></td>
</tr>
<tr>
<td>Metacognitive scaffold</td>
<td></td>
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<tr>
<td>Reflection scaffold</td>
<td></td>
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<tr>
<td>Sense making scaffold</td>
<td></td>
</tr>
<tr>
<td>Distributed learning support (not scaffold)</td>
<td></td>
</tr>
<tr>
<td>Control in hands of students – Independence script</td>
<td></td>
</tr>
<tr>
<td>Cognitive tool</td>
<td></td>
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<tr>
<td>Authentic activities</td>
<td></td>
</tr>
<tr>
<td>Presenting material from more than one perspective/modality</td>
<td></td>
</tr>
<tr>
<td>Confounding variables controlled by lab</td>
<td></td>
</tr>
</tbody>
</table>
**Design features in learning environment**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Ex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-structured problem</td>
<td>⬤ ⬤</td>
</tr>
<tr>
<td>Ill-structured problem</td>
<td>⬤</td>
</tr>
<tr>
<td>Learner-context interactions scripts</td>
<td>⬤ ⬤</td>
</tr>
<tr>
<td>Learn content to solve a problem</td>
<td>⬤</td>
</tr>
<tr>
<td>Accept multiple student explanations at beginning of lab</td>
<td>⬤</td>
</tr>
<tr>
<td>Virtual experiment (prepping equipment)</td>
<td>⬤ ⬤</td>
</tr>
<tr>
<td>Simulation (no prepping of equipment)</td>
<td>⬤</td>
</tr>
<tr>
<td>Manipulate materials (experiment)</td>
<td>⬤ ⬤</td>
</tr>
<tr>
<td>Observe actions (simulation)</td>
<td>⬤ ⬤</td>
</tr>
<tr>
<td>Reflection on experimental design for students</td>
<td>⬤</td>
</tr>
<tr>
<td>Acknowledge complexity of empirical work for students</td>
<td>⬤</td>
</tr>
<tr>
<td>Activating/asking about prior knowledge</td>
<td>⬤ ⬤</td>
</tr>
<tr>
<td>Everything housed in one-two</td>
<td>⬤ ⬤</td>
</tr>
<tr>
<td>Screen/window</td>
<td>Text-Lite</td>
</tr>
<tr>
<td>---------------</td>
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</tr>
<tr>
<td>Blended virtual simulation and home-physical lab</td>
<td>Em</td>
</tr>
<tr>
<td>Engaging Introduction</td>
<td>Em</td>
</tr>
<tr>
<td>Multiple opportunities to fail</td>
<td>Em</td>
</tr>
<tr>
<td>Dual navigation within the lab</td>
<td>Em</td>
</tr>
<tr>
<td>Gives students information on the equipment they are using</td>
<td>Em</td>
</tr>
<tr>
<td>Connecting students to the larger scientific community</td>
<td>Em</td>
</tr>
<tr>
<td>Incorporate videos directly into the lab</td>
<td>Em</td>
</tr>
<tr>
<td>Informal assessment built into the end of the lab</td>
<td>Em</td>
</tr>
<tr>
<td>Lab controls extraneous tasks for student</td>
<td>Em</td>
</tr>
<tr>
<td>Involves the parent/guardian in discussing the lab with their student</td>
<td>Em</td>
</tr>
<tr>
<td>Previously unobservable phenomena are visible</td>
<td>Em</td>
</tr>
<tr>
<td>Explicitly reduces time</td>
<td>Em</td>
</tr>
</tbody>
</table>
### Case Studies by School

**Cyber charter school A**

**Lab 1: 1.10 Conduction and Convection.** This lab is a Gizmo from ExploreLearning that is designed to help students understand conduction and convection of heat and minimize the heat transfer. The lab is introduced through the page in Figure 4.1, from the students’ learning management system. This lab gives examples of how heat transfer can be reduced in a couple of ways and guided directions for how to complete the virtual lab. The student is directed to open the virtual lab and download the student worksheet to guide their completion of the lab.

![Virtual Lab](https://via.placeholder.com/150)

*Figure 4.1.* This page introduces students to the lab and provides them the link to go to the lab.
The worksheet that accompanies the lab asks students to consider their prior knowledge before they begin the lab. These questions ask to consider pots on a stove and which type of handle they would rather touch and why and why something like soup gets hot first on the bottom of the pan. The worksheet then provides guided instruction to set-up the equipment for the lab. The setting up of equipment makes the lab an experiment rather than a simulation (Vrasidas, 2000). The worksheet focuses on the variables needed to manipulate and asks for description of what happens when the simulation is run. The descriptive sequences in the worksheet are easy to follow and the lab uses pictures to direct attention to the correct set-up based on the description. Figure 4.2 shows how the experiment was to be set-up and how the temperature changes over time with different materials separating the two flasks.

Figure 4.2. This shows how the worksheet instructed setting-up of the flask and what happens to the temperature that was originally set at two different temperatures.

The lab then helps learn how to read from a graph in the ‘data’ tab. This tab has students label what the graph is representing, and meets the computational science practice of the NGSS. The above was the warm-up activity to introduce features of the Gizmo. The lab has many of the
same activities as a scientist such as observing, hypothesizing, predicting, and analyzing the data for conclusions. There are scaffolding features to make the authentic practices of scientists more accessible. This is similar to what NGSS Appendix H espouses that inquiry methods should look like. The worksheet helps to structure the scientific investigation. The problem is not ill-structured because of the directions given in the worksheet, but the Gizmo itself could be ill-structured without these scaffolds and supports built-in. There are three activities on the worksheet but they all follow the same structure so one is described here as a representation of the activities. Activity A explores conduction. The lab has a ‘screenshot camera’ icon in the top right of the screen. This is a very useful feature and reduces navigation if students would need to take a picture of their experiment to send to their teacher. Taking a screenshot was not required for the directions to complete the lab from this school.

The student would not have to come up with a research question but rather answers one provided by the lab. The lab has the experimenter run a couple of different conductions with the flask with different stopper materials. This forms the background knowledge for the hypothesis that needs to be made. The hypothesis formation in the lab gives prompts to reflect on what materials would be good conductors and that considering this idea is part of the hypothesis to make sense of what conductor would cause the temperatures to change the fastest. The lab does not limit what can be entered for the hypothesis. Quinn et al., (2004) note that allowing for multiple hypotheses is important in virtual labs as there is not one hypothesis in the real world. The worksheet then has a data table to complete. The labels are filled in on the table but the data needs to be filled in after the experiment is run. Not requiring correct labeling reduces the confounding variables (Chen & Klahr, 1999) and ill-structured (Jonassen, 1997) nature of the problem in the lab. However, it also directs’ attention to the science practice of collecting data.
The question then becomes is learning how to appropriately label a graph a part of collecting data. This ideal structured case of reducing ill-structured problems was seen in 80% of the labs that Chen (2010) analyzed. The lab implicitly covers the crosscutting concepts of stability and change. Figure 4.3 shows the initial set-up of one the experiments that the worksheet prompted to be run.

![Figure 4.3. An example of the experimental set-up. This experiment needed to be run with solid copper, gold, lead, stone, glass, and rubber](image)

After all six of the experiments are run the lab worksheet prompts the determination of what substance allowed for the best heat conduction and using the data to explain this conclusion of the best heat conductor. The conclusion requires pattern-seeking between the different materials tested to see what the best conductors had in common. The conclusion signifies the end of the first lab for this Gizmo and the other two activities are very similar. The lab has a quick assessment to take but the school does not instruct students to take this assessment. After the lab,
students are expected to participate in a virtual discussion on the lab for the communicate section of this lesson. This communication is not analyzed with respect to the virtual science lab because it is an additional classroom activity that lives independently of the virtual lab software. However, it is still important to note the communication prompt because Hoadley (2000) emphasized how hard it is to design good discussion forums but the importance they have for students to see multiple perspectives. While communication was still absent from the actual lab it was in the same lesson sequence as the lab. I am not able to access the discussion boards in my role with the school. Figure 4.4 shows that the lab expects a discussion to take place after the lab is complete.

**Figure 4.4.** The last discussion forum is for the virtual lab completed for the unit.

**Lab 2 – Evolution: Natural and artificial selection gizmo.** This lab takes place in the unit on natural selection and adaptation. The learning objectives for the lab are to “summarize the way in which environmental pressures can change the characteristics of a population, explain
how genetic variation...can lead to evolution, and compare and contrast natural and artificial selection” (Learning objectives on lesson). Prior to this lab, the students are introduced to natural selection through text and videos. The introduction to the lab has questions to recall prior knowledge about natural selection in an informal manner. The lab specifies definitions for important words that will be encountered during the lab. This can be seen in Figure 4.5 that introduces the concept of natural selection and the important terms for the lab.

**Figure 4.5. Introduction to the natural and artificial selection lab for students**

The lab directions from the LMS has a worksheet to download to guide the experiment. This worksheet, seen in Appendix F of this study, illustrates the type of worksheets given for every ExploreLearning lab. The worksheet has prior knowledge questions to consider how dogs, like the dogs in the introduction to the lab in Figure 4.5, have different breeds. The worksheet specifies that prior knowledge activation needs to be done before beginning the labs. This activation of prior knowledge is important according to Seimars et al. (2012) in a constructivist
learning environment. This second Gizmo is structured the same way as the first lab analyzed from this school with prior knowledge and a warm-up to the lab. The warm-up to the lab helps introduce the script of the lab and how to use the worksheet as the descriptive sequence and the lab as the manipulation tool. The lab has no text embedded directly within the software. This lack of text embedded in the lab but incorporated into the static worksheet reduces the opportunity for contingent scaffolding from the lab or immediate feedback on answers to prompts. The worksheet has learning supports built in, such as highlighting or bolding important words or concepts. The lab directions direct the student to breed a set of insects and see how many offspring were produced. However, the script in the lab does not match the script in the worksheet as the lab then asks to choose 10 bugs to get rid of but the worksheet directs a different activity. Figure 4.6 is what the lab looks like after the warm-up activity is complete.

Figure 4.6. What the lab looks like after students complete the breeding warm-up activity

This dissonance between what the worksheet says and what the lab instructs could lead to confusion on when to stop the activity and shows an indexical rather than descriptive script
(Wettstein, 1979). The lab then has three different experiments to run. In this case, each experiment asks slightly different questions and labels procedures differently so each lab will be described in this specific study. The first lab is to learn about natural selection. The research question posed for this lab is “how are genes inherited and modified over many generations?” By posing the research question, this denotes the science practice as a half-donut in Table 4.4. In the observation section, the lab asks for observations of patterns in successive generations. The lab controls the script produce the right information needed for the analysis and conclusion section of the lab.

The analysis section of the lab illustrates the crosscutting concepts of structure and function by looking at genotype and phenotype. The lab focuses on learning content through problem solving as it introduces concepts that can be applied in the simulation. While the lab is not ill-structured as a problem with many possible outcomes, it does allow for multiple solutions or explanations for the phenomenon being observed. In the observe section after the analysis of genotype and phenotype, students need to write what they think is happening over many generations and mutations and the lab does not tell them what is happening to cause these changes. Figure 4.7 selects a bug to focus on the phenotype and genotype to determine if the mutation is harmful, neutral, or beneficial.
Figure 4.7. Analysis of the phenotype and genotype of a mutated bug to conjecture on if this mutation is beneficial, harmful, or neutral

The lab expects explicit understanding of patterns and relationships from interacting with and observing the simulation. This can be seen from the questions asked in the lab. These metacognitive, sense-making prompts focus on reflections of what is known and how to apply what was learned in the lab to the summary questions about the lab. In terms of science practices, there is no expectation or prompt for engaging in argument from evidence at the end of the lab or for communicating conclusions from the labs. The second lab transitions from natural to artificial selection. This lab provides more independence (Vrasidas, 2000) as it allows for manipulation of the color of insects and for the expectation that the student comes up with the procedures. This lab is ill-structured as there are multiple outcomes and uncertainties (Jonassen, 1997). The lab prompts students to hypothesize and infer from the simulation to answer the questions found on the worksheet in Appendix F at the end of this study. The lab subtly
acknowledges the complexity of empirical work when it stresses that running a Gizmo based on the student making their own hypothesis and deciding on the procedures takes patience. The lab promotes communication with prompts that urge students to talk with their peers about the results that they see. Figure 4.8 shows the results of an experiment that I ran when deciding the hypothesis and procedures.

![Figure 4.8. The result of the experiment where I set the controls, procedures, and variables according to the instructions of the Gizmo.](image)

The lab brings prior knowledge back into the narrative by applying what was just learned from running an independent experiment on artificial selection and now applying it to two drastically different dog breeds. One limitation of these labs is that the answers to the worksheet are in a different window than the lab and thus formative assessment could not be understood as the lab is being completed. In a F2F classroom this would not be an issue as the teacher could stop during important points and assess this, but in a virtual setting have these feedback mechanisms built into the lab are very important to help students self-regulate their learning.
(Van den Boom et al., 2004). The lab prompts for collection of data and linked conclusions to the data about how long natural selection takes to develop a healthy fitness for a population and then compare whether artificial or natural selection will happen faster in this population.

The final lab is to look at and understand mutation rates. This lab poses questions to answer. The lab is run with different mutation rates to see how many mutations appear under different rates. In all of these labs there are multiple opportunities to fail, the lab can be navigated in a variety of ways, and the reset button can be pressed to start over. These are all emergent categories from this analysis. These features are important for learning in an environment without pressure for failure and resembles a mastery-based learning environment (Block & Burns, 1976) that the teachers from these schools also embraced through allowing for multiple submissions and revisions until students ‘got it’. Figure 4.9 specifies one of the mutation rates needed to be run for collection of data.

![Image](image.png)

**Figure 4.9.** One of the mutation rates that students need to run to collect data

Three sample mutation rates are run and then a hypothesis is formed to collect more data on mutation rates and represent this data in tabular form. This lab prompts for the analysis of
results and communication of findings with peers and the instructor in the course. In step 6 of activity C in Appendix F of this study there is a prompt for engaging in argument from evidence. The final activity of the lab is to create a population of insects that maintain a healthy fitness applying what has been learned from the first two Gizmo experiments. This is a culminating activity that requires application of prior knowledge accumulated in the lab to conduct an independent investigation. Seimers et al., (2012) identify activating prior knowledge as essential for a constructivist learning environment.

**Lab 3 - Directed virtual labs: Mendel’s experiments 101.** This lab is part of lesson 2 on inheritance and traits. Rather than being titled an ‘explore’ page in the LMS this lab is under a ‘communicate, collaborate, and connect’ heading. It is not clear from any description or organization why this would be under communicate rather than explore. Figure 4.10 shows how this is under the ‘communicate, collaborate, and connect’ heading.
This lab is from a Pearson Digital Path resource. The introduction to this lab is different than the previous ExploreLearning labs that this school used. There is a notebook that needs kept while the lab is being completed and the notebook is built directly into the lab software. Figure 4.11 shows the lab starting out with a simulation of looking like a traditional physical laboratory.
The experiment starts with reading about the history of genetics with Gregor Mendel. This background information highlights the main finding that Mendel found and that the goal of this lab is to simulate Mendel’s experiments. The navigation bar on the right side of the lab allows for dual navigation and keeps track of the progress of the virtual lab. Videos are embedded in the lab to cover Mendel’s pea plants and how to form a hypothesis. The videos are short (all less than 2:30). Hsin and Cigas (2013) note that the use of short instructional videos increased student persistence and satisfaction in their online course. A limitation of this lab is that it is not responsive to the size of the device. When I adjust my browser window the lab does not adjust to the size of the window and thus some features are lost such as the navigation when the window is too small. Figure 4.12 shows the limitation of the lab in being responsive to the size of device that is used to access the lab.

Figure 4.12. Example of the screen not being responsive to the size of my device
Figure 4.12 also shows a prompt for entering the hypothesis directly into the lab. After the answer is entered the lab does not acknowledge or respond to what was typed into the textbox. The script is descriptive and directed so there is very little room for independence in the hands of the learner or ill-structured problem solving. The lab presents the information in multiple modalities as there is both text and audio for some of the slides, as well as videos embedded within the lab. Figure 4.13 shows how this information is displayed in multiple ways as the ‘play’ button plays audio of what is seen in the graph.

Figure 4.13. The play button on the left hand side prevents information to students in multiple ways

The videos provide detailed information on concepts such as dominant and recessive alleles before moving into the remainder of the lab. However, it is impossible to know if this information is within the students’ ZPD (Tuysuz, 2011) and the lab does not assess student understanding of this before beginning the videos. There are prompts to fill out within the lab, but it is possible to proceed through the navigation of the lab without actually completing any of the prompts or interacting with the lab window. In this sense the lab gives control, but not independence in how they lab can be interacted with besides the navigation buttons. The lab procedures to be completed are set-up by the lab and do not require any control or independence
to make decisions on what variables to use, procedures to run, or how the lab will be set-up. This is what Crippen et al., (2012) described as a simulation and observation. The information discussed in the video on which parent allele was dominant and recessive is stated in the video before every simulation but is not included in the graph where interpretation based on these concepts is expected. There is a lack of descriptives in the script for this section of the lab (Wettstein, 1979). The design of the video is not clear because it is just a graph and software that the students are not actually working with so it remains abstract and not concrete. It is a general video of the software but not related to the procedures of this lab. Figure 4.14 shows a video that would be watched of an example simulated experiment.

![Mendel's Experiments 101](image)

*Figure 4.14. The video showing an example of the simulated experiment the students will interpret*

This video does not connect with prior knowledge and is not authentic in the sense that in the real world scientists will need to actually run the simulation to determine the genetics of offspring. Prior knowledge and authentic activities are both essential to constructivist learning environments (Seimers et al., 2004; Wilson, 2006). The lab runs the simulation without user
actions. The penultimate slide asks whether a large or small sample size is preferable. This has the potential to have reflection on experimental design but the prompt does not structure reflective thought in terms of experimental design or provide immediate feedback based on the textbox answer to a large or small sample. The prompts for every text is to explain the reasoning. This reasoning is dependent on recall from the videos. Asking to explain the reasoning is similar to the general prompts that Davis (2003) studied with metacognition. If the videos and simulation questions were on the same page this would reduce the off-task cognitive load because the resources could be looked at holistically, rather than having to navigate through the lab. The final slide of this lab congratulates students for completing the questions but does not give feedback on their answers. Answers can be compared to the accepted answers in the school’s LMS. However, this requires answers to be entered in both the science notebook and in the lab notebook. Also, these only give one possible answer except for the hypothesis and then it simply states that the hypothesis will vary. This does not allow for multiple explanations or answers, nor does it guide the basics of hypothesis-formation while accepting multiple hypotheses. The answers do explicitly address the crosscutting concept of patterns in genetics.

**Lab 4 – 3.3 Mouse genetics (one trait).** This lab is an ExploreLearning Gizmo and is found under the ‘communicate, collaborate, and connect’ tab in the LMS. The learning objective for this lab is for students to apply what the lesson has so far taught them about probability and heredity. The directions specify that the student exploration sheet needs to be completed. The directions also specify that the student should discuss specific questions with their learning coach. This learning coach is intended to be a parent or guardian. Figure 4.15 shows how the LMS prompts students to communicate about this lab with their learning coach.
Figure 4.15. Introducing students to the lab they will be completing for probability and heredity

The lab starts in the same way as the other two ExploreLearning Gizmos used in this school with the prior knowledge questions that introduce these abstract concepts through looking at physical characteristics and variations in a litter of kittens. There is a warm-up section to practice with the Gizmo that introduces concepts and asks for recall of prior knowledge. This is done in a way that resembles a cognitive tool in virtual labs (Jonassen et al., 1997; van Joolingen et al., 2007).

This lab requires set-up the experiment before going through authentic science processes such as predicting and experimenting. Figure 4.16 shows how the lab needs to be set-up to meet the designated learning objectives.
Figure 4.16. Set-up of the virtual lab as directed by the student worksheet

The first lab requires breeding of the parents, producing hybrids, and then breeding those hybrids. The lab uses computational thinking by having a ‘show statistics’ option appear so that the changing genotypes are illustrated when the phenotypes change. This lab is directed and dictates what procedures to run for the first experiment. After this experiment, the lab encourages using different mice parent colors to see how those offspring are similar or different. This lab controls the variables by focusing only on one trait for the mice offspring. This does not prevent manipulation of the variable of color or what mice offspring to keep but provides a simplified introduction to genetics. This helps introduce authentic activities and expertise of scientists through scaffolding and focusing (Bransford et al., 2006). The lab does not have authentic practices the same way that a scientist in the field would do them, but scaffolds the practices to different developmental levels. The lab promotes communication through a challenge where students would need to come up with their own theory of inheritance based on their observations.
The lab then instructs to share this theory with peers or teachers. The script on the introduction to the lab focuses on communication to discuss findings with the learning coach. Figure 4.17 shows how the first lab was run and the recessive white mouse that appeared in the offspring.

![Figure 4.17. An example of the first lab for mouse genetics outcome](image)

The second lab requires set-up of the lab and introduces the concepts of DNA and alleles. The research question posed in this section is “how do alleles determine fur color?” This is a partially present science practice because while it addresses the research question it is automatically provided to students. The lab requires observation of basic information about mice in terms of their genotype and applying vocabulary and content through determining the genotypes of the mice. This section of the lab is very structured and gives clear directions in order to increase the likelihood that desired results are obtained from the lab. At the same time, the lab gives a certain level of independence as it requires decisions on how many breeding simulations to run. The lab does not scaffold this decision of simulations to run by considering
the benefits of a large sample size. This lab ends after the experiment and does not have any analyzing of data, modeling of concepts, or concluding of the experiment.

The final mouse genetics lab is shows how to model inheritance. This lab starts with building on knowledge that should have been gained from the first two mouse genetics lab. The students are asked to predict the number of black and white offspring and their genotypes and then compare this prediction to what actually happens in the experiment. Figure 4.18 shows the start of the final experiment in the mouse genetics lab.

![Figure 4.18](image-url)

Figure 4.18. The start of the third lab. This was related to experiments in the first two labs

The lab gets increasingly complicated in terms of experimentation and control of the lab because the user is responsible for determining which mice should be help according to the phenotype of those mice. An experiment needs to be run to analyze the percentage of white and black offspring with a hybrid cross two times. The lab does not ask why the same experiment with the same genotype is being run two different times (500 mice each time are bred). This misses the opportunity to explicitly ask questions about experimental design or experimental
error. In his content analysis of PhET virtual labs, Chen (2010) only found 1% of labs that asked students to reflect on experimental design/error.

After the experiment is run 500 times for each set of hybrid mice the lab asks for explanations of heredity based on the experiments that students run. The final step in this lab is to think and discuss what has been learned from heredity in this lab by applying it to fur of other animals for traits. The lab does not specify who the student should discuss their ideas with. The script in the LMS before the lab does not instruct students to take the assessment questions under the lab simulation. An example of an assessment question is seen in Figure 4.19. At the end of the lab the LMS states that there is link that provides an answer key to the student exploration. In actuality, this link goes to the assessment questions. This is an indexical rather than descriptive script (Wettstein, 1979) because it is not clear what part of the lab this links is referring to. The assessment in the actual lab goes beyond the right answers to explaining why the answer is correct and provides immediate feedback on if the post-lab assessment questions were answered correctly and why. Feedback is important for student learning in a constructivist environment (van Den Boom et al., 2004). The assessment question answers provide immediate feedback.
The design of every single lesson in Cyber Charter School A is consistent in the LMS and designed to support many features of constructivist learning environments and supports. For example, there is a descriptive label on the top left of every page that tells what this page is designed to accomplish as can be seen in Figure 4.20. The ‘connect and collaborate’ page does not always have interaction or discussion but does have connections between what was learned in the lab and the real world. For example, with the conduction and convection lab the prompt was to design a device that minimizes heat transfer and explain the reasoning for a company that
theoretically hired the students to design this device. Figure 4.20 shows the uniformity in the design of the pages in the LMS.

**Figure 4.20.** Every page in the course is set-up the same and prompts students for activating prior knowledge, helps them to explore, and always ends with a communicate, connect, and collaborate section.

While the school has a few virtual labs that have students do something at home, these were not as common with the life science content where there were many virtual labs to complete. Since the initial intention of this study was on virtual labs and specifically life science virtual labs these virtual labs were selected to study. Interestingly, the school does not refer to these as virtual labs and rather calls them practice to apply the concepts that they have learned in these units or portfolios.

In terms of science practices, none of the labs ask for research questions from the students, but three of the labs allow for designing experiments later in the lab. While these labs never explicitly ask for research questions, a research question is needed to design the lab. However, the labs never explicitly ask for research questions to see if the students who would complete the labs are able to form them. Three of the four labs reached at least seven of the eight
science practices. The only lab that did not reach seven of the science practices reached five of the eight (Mendel genetics lab).

In terms of crosscutting concepts, the labs trended towards including many crosscutting concepts but being explicit in few. Considering Quinn et al. (2012) emphasize the importance of making crosscutting concepts explicit these labs do not frequently reach that ideal. Patterns were explicitly identified in all of the labs except for the conduction and convection lab. The labs were lacking in the crosscutting concepts on systems and system models and energy and matter. However, at least one lab hit all of the cross cutting concepts although many times this was implicit in the design.

A particular strength of these virtual labs is their ability to foster communication and have prompts that ask about thinking about how a student would respond to what they learned in the lab. Hoadley (2000) emphasizes the importance of communication in exposing students to other experiences and this lab was designed to prepare students to do this. Now, it is not actually known if students communicate but this is an area that could be explored through qualitative research with the students. All of these labs had some form of scaffolding in terms of channeling and modeling. A fading scaffold was not identified in any of the virtual labs.

The labs were all cognitive tools because they had prompts and designs that helped to externalize thinking. The labs did not present the material from more than one modality except for the Mendel genetics lab which included audio and text. The confounding variables were controlled by the labs for some sections, but were designed to have control of the lab in the hands of the student by the end of the lab... While the labs accepted multiple explanations (except Mendel) they did not have prompt feedback to respond to hypothetical student responses. A large component of doing science in a physical sense that is missing from every one of these
labs is a focus on equipment and what equipment would be used to accomplish this in a physical science lab. Scientists cannot complete investigations without tools and this is a large part of ‘doing’ science. As Chen (2010) found in the majority of his labs in the PhET content analysis, the labs in this study do not ask students to reflect on experimental design or recognize complexity with the exception of one lab.

The emerging categories from this lab were informal assessment built into the lab, lab controlling for extraneous tasks to focus student attention, and involving the parent or guardian in the students’ education. This final point is very interesting when considering from the teacher interviews that there is at the very least a desire from the teachers for the parents to be more involved, but an overall disappointment with how active the parents actually are. Parents in cyber charter schools provide a close proximity (theoretically) person that the students could communicate with about their virtual labs rather than completing the labs in isolation and are expected to be involved in their students education (Huerta et al., 2006).

**Cyber Charter School B Case Study**

**Lab 1 – Blood typing activity.** This lab comes from NobelPrize.org which is the Web site of the Nobel Prize according to the Web site. The Web site refers to this lab as a game. The introduction to this lab involves a seen to show the need to learn how to do blood typing. This job places the student in the role of the scientist who needs to rapidly identify the blood type of three people who were just in a bad car accident. The introduction to the lab is engaging for students. Figure 4.21 shows the introduction to the lab and what the goal of the lab is.
Figure 4.21. This image introduces the goal for the lab.

The lab is interactive and a cognitive tool that requires application of prior knowledge to solve the problem within the lab. The learner-context interaction requires the students who will be completing the lab to use their own knowledge when interacting with the lab and provides multiple ways to go about solving the problem of identifying the correct blood type. When a patient is clicked on from the initial screen it takes them into the operating room where the lab asks for the right type of blood for the blood transfusion. Figure 4.22 shows how the operating room is depicted in the lab.
Figure 4.22. This is the operating room where students will need to correctly identify the type of blood for a blood transfusion.

The lab is ill-structured and provides a significant amount of independence. The lab does not provide direction for taking a sample of blood to identify the blood type but does provide a directional scaffold to show how to dispense the blood in the correct test tube. Figure 4.23 shows the scaffold with how to properly put the blood into the test tube.
Figure 4.23. The direct scaffold that provides guidance to the student on how to mix the blood typing.

Once the reagents are combined the lab requires interacting to figure out what each bag of blood is from the information on the bag. Each bag then tells what will happen if a person without that type of blood is given that type of blood. The level of information provided does not take into account the students’ prior knowledge and does not contain any feedback boxes or ways for students to state why they are giving the patient the type of blood they gave them. Any bag of blood can be selected but if the wrong type of blood is chosen then the patient will convulse. At that point, a different bag of blood can be chosen and the lab provides a scaffolded direct prompt to give more direction on what type of blood should be chosen. When the correct bag of blood is identified the lab puts this bag of blood on the medicine pole and the next patient
can be worked on. The lab is ill-structured and gives a significant amount of independence in the script by having the student able to experiment and reset any patient in any order.

The lab then proceeds to bring in the next two patients and have the same problem to solve of identifying the correct blood type. Each patient has slightly different needs. For example, the girl in Figure 4.24 is noted to be in poor shape.

![Figure 4.24](image)

*Figure 4.24. An example of a patient that the student has to give the correct blood too.*

The lab is able to use fading scaffolds because as each patient comes in the blood reacts the same way in the reagent tubes and if a mistake is made and the patient is given the wrong blood in a prior patient there can be recall of what the blood did to the patient. Scaffolds are also seen in other virtual labs (Pyatt & Sims, 2011) and support students in their learning. The lab does not give any direction on which order to work with the patients. When I completed the lab, the third patient ended up being the most difficult to treat but it is possible that a student would choose this patient as the first patient and not have the prior experience from the other patients to
figure out what type of blood she can receive. From my experience with the lab, the scaffolds and modeling in the ill-structured section helped to develop understanding of blood types and what happens in blood transfusions. The lab also covertly controlled confounding variables and allowed for focus of the task of deciding which blood to deliver to the patient. At the conclusion of the lab the students are invited to the party and given brief feedback on how they performed in the lab. Figure 4.25 shows the party room and the feedback that the students are given.

Figure 4.25. The brief feedback for students on how they performed in the blood typing lab.

The lab is limiting in its ability to allow communication about the lab to peers or instructors. In addition the lab does not encompass the majority of science practices because there is no hypothesis or conclusion prompt. The reasoning behind the lab requires thinking
about which blood would work and why but there is no place for documenting this thinking or getting feedback from the lab except for at the very end of the lab in the party scene. The ability to make multiple mistakes and fail in the lab without real-world repercussions was particularly evident (Gee, 2007). This lab was titled a game and it did have game-like features in that it was addicting to figure out, gave independence and ownership over what the students would be doing (Gee, 2007). However, the environment still had a design beyond what the student chose as they was not a chance to ask research questions, articulate the hypothesis, or express understanding during the lab.

**Lab 2 – Testing and adjusting pH.** This is the second lab in a series of labs that this teacher uses to teach about controlling pH. The lab starts with an introduction to the problem that needs to be solved which is to prevent food from spoiling with contamination.

![Figure 4.26](image.jpg)

*Figure 4.26.* This is the introduction to the lab and provides an underlying structure and goal for this lab.

The lab then proceeds to provide the descriptive sequence needed for background information on the lab. The lab identifies the type of food needed to preserve and the possible
pathogen that can cause this food to spoil. Figure 4.27 shows the name of this pathogen, *Clostridium Botulinum*.

*Figure 4.27.* Introducing the pathogen that can make people sick by foodborne illness.

The lab has a script that forces attention on certain aspects of the lab. For example, on the third page the students need to zoom-in on the bacteria pictured in Figure 4.27. This can help students to channel their attention (Pea, 2004). The descriptive sequence in this lab explains well to the context and uses multiple ways to make this information clear including preventing moving on until certain text has been read and providing a clear understanding of the story and problem to be solved. This lab also can be considered ‘text-lite’ as the text is never more than one bubble per page and is always accompanied by an illustration as can be seen in Figure 4.28.
Figure 4.28. An example of the ‘text-lite’ emphasis in this lab with illustrations to explain the script to students.

The next page explains how heat is not the correct process needed to prevent this bacteria from growing. This descriptive sequence is not as clear because it explains that “even though heat processing is important, cooking the salsa before canning it won’t destroy *C. bot.*” Students are not asked to predict why the heat process is important for overall food safety. There is a camera icon below this text that explains why, but the lab does not direct or require clicking of this icon. The lab describes why simply vacuum sealing the salsa jars would not work for prevention of bacteria growth due to the unique characteristic that it will only grow in the absence of oxygen. The lab does not allow students to assert their understanding or provide feedback as to what the students would be thinking as they go through the virtual lab. The lab then introduces the technique needed to lower the pH and make the salsa safe from *C. bot.* Figure 4.29 shows the goal for this lab.
Figure 4.29. This image outlines the goal for this lab: To add acid to the salsa to lower the pH.

The scenario in Figure 4.29 would provide a good opportunity for students to be able to decide which pH they should actually shoot for and explain why it would be better to go below the minimum pH but the script in this lab does not grant that level of independence to the students (Vrasidas, 2000). This is similar to the design in 80% of the labs Chen (2010) found in his PhET content analysis. The next sequences provides the first chance to interact with the lab beyond pressing a button to read more about the introduction to the lab. The lab requires a decision between the two types of acid to add to the salsa so the bacteria does not grow. Once the acid is chosen (vinegar or lemon juice) the lab requires making of the salsa using different amounts of acid. This lab addresses certain science practices such as designing and controlling an investigation, but others are still lacking such as communicating information or having students ask their own question. The lab gives control over the problem but limits the ill-
structured nature of the problem by providing labeling and telling how much acid needed to be added. Figure 4.30 shows the lab telling how much acid to add to the salsa.

![Image of lab](image.png)

Figure 4.30. The lab limited for students the choices and ability to fail as it predetermined how students could interact with the lab.

The lab controls the confounding variables and thus does not allow for the chance of metacognition where students think and determine which variables to control (Klahr & Dunbar, 1998). The lab directs that the next step is to test the pH. A limitation in the design of this lab is that the navigation does not allow for going back to prior screens once the next button has been clicked. Therefore, dual navigation is not present. The script for the lab connotes a false sense of independence and multiple processes that the student would be controlling. For example, the lab says to “blend on high speed until the solution appears to be homogenous.” However, the lab does the blending without action from the user and makes the decision for when the solution has been mixed and is homogenious. Once all of the samples have been prepared the students are
instructed that they will take readings of the samples to determine what the pH is. Figure 4.31 shows what will happen to take the samples from each salsa.

Figure 4.31. Preparing the lab to test the pH of all of the samples.

The lab introduces some concepts that are important to the field of science such as being precise in what is being measured. This is important to both science practices of carrying out the investigation and making sure that the analysis of the data is correct. The next couple of slides give instructions on how to work the pH meter and show the buttons that are important to use during the collection of data. When the pH meter is inserted into the samples the lab says to keep stirring so that the pH reading is accurate. To situate this as more of an ill-structured problem with multiple outcomes the lab could first have required use of the pH meter to think about what technique could provide optimal results, provide a feedback box for a student to enter how they thought about the technique, and scaffolded based on the student response. Figure 4.32 shows limited use of the pH meter.
Figure 4.32. This interactive allows for use of the pH meter but limits how they can use it.

After the meter is cleaned and a second reading is taken from sample 1a, the lab gives instructions to record this reading in the lab notebook. However, the virtual lab does not provide a notebook built into the lab. The lab does not have that capacity and is assuming that the students will have an alternate way of recording data and using the notebook. Figure 4.33 shows how the measurements should be recorded in the lab notebook.
Figure 4.33. Directions from the lab to show students the information that needs to be recorded in the notebook.

After the students would complete the first test with sample one, the lab does the testing with samples two and three by themselves and goes through the motions so quickly that the I could not even see what the measurements are as they are being recorded. The lab does explicitly reduce the time for completion of the lab but does not stop to check for understanding during the entire lab. From personal experience completing this lab, the lab taking over some of the procedures made me feel like I was not needed to conduct the lab and it was a simulation I could just watch. The script states that “in a lab setting this process would need to be repeated twice.” The lab provides information on how the equipment being used is stored and maintained which replaces the fact that all the virtual labs do not have physical manipulation of the equipment. The American Chemical Society maintains that this hands-on manipulation is important for preparing students in science and technology careers (ACS, 2016). This lab and all virtual labs do not allow for hands-on manipulation, but can provide the context under when and which this manipulation
could occur. When the results are being interpreted, the lab asks which acid amount will make
the salsa have a safe pH but does not prompt for engaging in arguments or communicating
results. When selecting the proper result the lab gives you a choice of three samples. If the wrong
sample is selected the lab has a window appear that guides why that was the incorrect answer
and allows for trying again to get the correct answer. Figure 4.34 shows how the lab guides
thinking so that a sample is chosen that will result in less invasive testing.

Figure 4.34. The screen shown if the wrong sample of acid is selected.

The lab hints at the complexity of scientific work after the correct sample is selected by
saying that “we may decide to run more samples of A2 to perfect our method. Other food science
workers will perfect the salsa in other ways.” However, it does not acknowledge the complexity
of determining accurate pH levels in this lab or ask what some of the other methods could be to
determine food safety. The lab then proceeds to the next process in developing a safe food
product which is a taste test. The lab makes a weak connection to the scientific community
through the script as it shows what will happen after the pH levels have been made safe and how the community accepts a food as safe. However, students would not be expected to contribute any of their own knowledge or information to this community. The lab concludes by emphasizing that testing of pH will need to occur when larger batches of salsa are made and then goes back to the beginning of the lab. There is no chance for reflection on a hypothesis or articulating their understandings and perspectives of what they learned from this lab.

**Lab 3 – Virtual frog dissection.** This lab comes from a McGraw Hill virtual lab and has students virtually dissect a frog. The learning objectives for the lab are to learn to use the tools for dissections, the techniques for dissections, what the frog looks like externally, what the major organ systems of a frog are, and to compare the anatomy of a frog to the anatomy of a human. The lab is very text-lite from the beginning and has an image of a frog in the position the frog would be in from a physical dissection. Most of the script is provided through narration. The lab starts by engaging with the question of what our insides look like after we digest food and then how we can learn something about the human body from looking inside a frog. The lab does not ask for hypotheses on what may be seen in the frog dissection, what the inside of a frog may look like, or if it will be similar or different to pictures of the inside of a human. Figure 4.35 shows the introduction to the virtual frog dissection. Figure 4.36 shows what the learning outcomes of the lab will be pictorially.
Figure 4.35. Introducing students to the virtual frog dissection they will complete.

Figure 4.36. The learning outcomes at the conclusion of the lab represented pictorially.

The lab shows a 3d video that tells about the structure of the frog. The narration speaks quickly and it would be virtually impossible to take notes the first time the narration is listened to. However, the lab allows multi-directional navigation to go back to any part that was not
understood the first time. This is reliant on the students who would be completing the lab realizing that they do not understand everything the navigation said. The lab then tells about the classification of animals and why frogs are in the amphibian classification because of the double life phase cycle. The lab does not connect how this will be relevant information to remember during the dissection. The lab does not allow choice in which species of frog will be dissected but rather tells students that they will use this frog for their dissection. Figure 4.37 shows what species of frog is going to be used for this dissection.

![Image of frog for dissection](image)

Figure 4.37. The species of frog that will be used for this dissection.

The graphics used in this lab reduce the authenticity of the lab. If the lab used real pictures of the frog and instruments the lab would be more authentic to physically dissecting a frog. The lab does not require watching of any of the videos embedded in the lab that explains what would be done in the lab and the ‘next’ arrow at the bottom of the screen can be clicked as soon as the page loads. When the introduction is complete it is not clear in the descriptive
sequence what should be clicked to get to the next part of the lab. The ‘next’ arrow is not clickable but the lab does not say to return to the menu to select the next section.

There is no opportunity for stating prior knowledge or assumptions that a student may have about what a frog dissection will be like. Seimers et al. (2012) emphasizes how articulating prior knowledge can help students to build and connect on what they are going to learn. There is not a place for checking for understanding and the lab does not have any guides to focus on what is important. The lab has many learning outcomes and it became overwhelming to keep these in mind while also completing the required procedures to dissect the frog. For example, the introduction to the lab mentions animal classification and the difference between human and amphibian but with one of the learning outcomes being understanding how a frog dissection can help us to understand the anatomy of a human the lab does not make this clear in any of the introduction. The lab introduces the different body terms that can be used to identify the lab but does not allow for active interaction with the frog or correctly matching the terms to the right body part. This type of prompting could help to activate students’ metacognition (Azevedo & Hadwin, 2005) and scaffold their learning in the science lab. Figure 4.38 shows how the frog would look from the ventral view.
The skin is emphasized because it can help the frog with respiration and has mucus to help keep the skin moist. The connection between the importance of keeping our lungs healthy and moist and a frog’s skin healthy and moist is not made for students. The NGSS emphasize that the crosscutting concepts need to be made explicit. This is a ‘structure and function’ crosscutting concept but it is not made explicit in the lab. The lab then described the structure of the head, cloaca, and legs for the frog and the function they play in the frog’s life. The lab presents a significant amount of information in the script without providing a notebook or prompt to check their understanding periodically through the lab. The transmission of information without active learning is similar to instructionist pedagogy (Sawyer, 2006). This concluded the external anatomy of the frog. To this point there has been no interaction with the lab beyond clicking on the next or play arrow. The internal anatomy starts the active part of the investigation. Figure 4.39 shows the beginning of the actual dissection.
Figure 4.39. The beginning of the dissection for students.

The lab becomes much more authentic here as the video shows an actual frog in the dissecting pan and how this frog will be dissected. While in the cyber charter school there will probably not be a chance to physically dissect a frog, this lab does an excellent job of showing these tools and the procedures that need to be done to physically cut the frog for beginning the dissection. However, the lab has a very long video for opening the body for dissection without allowing for watching one step and then practicing with the dissecting cut for that step. When it is time for the actual dissection the lab does not allow for actual manipulation of the tools. Once the tool is selected the lab design completes the dissection. It is entirely possible to complete the dissection without actually selecting any tool and just selecting the next button. Figure 4.40 shows what the frog looks like after the initial cut.
While the lab is instructing how to make the cuts it is not explaining or asking for input on why students might think that they are completing these procedures. The lab has distributed learning supports in the sense that when it is time for an action to be completed the right tool is highlighted in blue as can be seen from the scissor icon in Figure 4.41. The next body system identified is the digestive system. The lab tells all of the important parts of the frog but does not provide any scaffold or help to remember these terms to understand why these dissection steps are occurring. This frog dissection takes place in a very well-structured-problem zone because there is no independence in how a student could interact with the frog and the lab requires specific steps to be followed. The narration prompts to remove organs so that the lower organ systems can also be seen. This meets their learning objective of introducing the eight major organ systems. The lab does not require manipulation to select the correct organ as once the
tweezers are chosen, the right organ is automatically removed from the body. The organs stay in sight on the dissecting pan so that what it looks like outside of the body can be seen. Figure 4.41 shows the organs outside of the body.

Figure 4.41. Digestive system of the frog. Organs seen outside of the body.

The remainder of the organ system steps functioned in much the same way as the digestive system in that there was minimal independence in the script (Vrasidas, 2000), scaffolds were not provided (Pea, 2004), there were no prompts for articulating understanding (Sawyer, 2006) and the lab did not require actually clicking on anything besides the next button to move through the lab. The lab did an excellent job of explaining in detail all of the organ systems but without self-check assessments or allowing student input with the lab it is not possible for the lab to know if students are understanding what is occurring nor is it possible to provide contingent scaffolds based on an individual students’ level of understanding. When the lab is
focusing on a specific organ system there are graphic design features such as highlighting the female organ system in Figure 4.42 to make it explicit that that is the organ system being used.

![Image](image.png)

*Figure 4.42.* The female reproductive system highlighted for the students.

The lab ends at the conclusion of dissecting the skeletal system. The lab does not ask for discussion about the tools that were learned about to do dissections, comment on the organ systems that were learned about, or hypothesize on the similarities and differences between a frog in the amphibian class and a human in the mammalian class. This lab was strong in some aspects such as showing an actual dissection at and having clear learning objectives, but the design of the lab with relatively passive movements, no scaffolds, and a script that was not independent limited the open-ended and complex nature of completing a dissection. In addition, there were no sense-making prompts to help them make sense and synthesize what was experienced in the lab.
It is worth noting that this teacher previously used a different frog dissection that was open-ended in terms of how students could interact with the material but the software changed so that it was not open-access and this forced her to choose a different software.

**Lab 4 – PhET natural selection.** The final lab selected for this cyber charter school is the PhET Natural Selection Lab. PhET labs come from the University of Colorado and these is the lab software that Chen (2010) analyzed in his content analysis of virtual labs. This lab is a very open ended and ill-structured lab that allows for control of many variables at the same time. Figure 4.43 shows the set-up of the lab before any actions were taken.

![Figure 4.43. How the natural selection lab looks when the program first loads.](image)

If I did not choose to add a mutation, change genes, or add resources to the environment the bunny will die and then I had the opportunity to play the simulation again. There are many opportunities to fail in this lab. The student could add many mutations at once, can change the selection factors, and the environment all at the same time. When interacting with the virtual lab
it is hard to discern how the specific action is affecting the bunny population. The labs are student-centered and process-oriented rather than finding a specific answer for the lab (PhET activity guidelines). Fuhrman et al. (1978) reflect on this as a lab focusing on inquiry rather than learning specific content. There are rules that appear as exploration with the lab continues. For example, if no actions are taken but adding a friend the bunnies will eventually overpopulate to the point that they ‘take over the earth’. Figure 4.44 shows the overpopulation of bunnies.

Figure 4.44. Bunnies take over the world when there are no factors placed on natural selection.

The lab does not have any built-in scaffolds or reflection mechanisms to demonstrate understanding or what the students would be thinking while they complete the lab. This lab, with its ill-structured nature and focus on exploring rather than answers, absolutely has the potential to engage students in several science practices. However, this depends on the teacher to design a worksheet around the lesson as the lab does not come with any of these designs built-in. The
population of bunnies can be viewed from many different perspectives. For example, the bunnies can be viewed by a graph showing bunny population over time or by a pedigree that shows where a bunny comes from and the success of its’ pedigree. One limitation of this lab is that it is impossible to slow down the time until the next generation of bunnies. If this feature was able to be controlled then it would allow them more time to see how different variables can affect natural selection. The lab could have a prompt that appears to show that the scale of natural selection depends on many factors and we cannot artificially control the time that it takes a population to develop and change in nature.

The lab very clearly demonstrates the effects of the environment on natural selection. For example, when brown fur is selected as the dominant trait the bunnies mutate to have a certain percentage of them have brown hair. If the bunnies are then selected to live in the arctic and given an enemy of wolves the brown bunnies will be eaten at a much faster rate than the white bunnies. Figure 4.45 shows how being in the arctic is not advantageous to the brown bunnies.
Figure 4.45. An example of how the bunnies could be changed to study natural selection. The wolves eat the brown bunnies in an arctic environment.

If a bunny comes from a pedigree that has a mutation that bunny will have a caution sign above it to show that it was the carrier of that gene which became dominant and now showed up in the population. Overall this lab has the potential to engage students in many science practices and make crosscutting concepts explicit but the lab itself does not contain many of the constructivist supports needed to help students in their inquiry and open-ended exploration. These labs are dependent on the teacher to support students in their exploration or they risk becoming a pure discovery-based learning environment (Mayer, 2004). Therefore when looking at Table 4.4 that provides the matrix of features the crosscutting concepts are filled in with a half-donut to indicate the potential is there but they are not made explicit in the labs because it requires implicit inferring.
Summary Cyber Charter B

This teacher takes advantage of any free and open labs because of a lack of subscription to virtual lab software. The labs used in this school have the potential to engage students with six of the eight science practices. The limiting features in these labs are very similar to limitations in the other schools because the labs do not prompt for engaging in argument from evidence, or obtain and communicate information. The context surrounding the labs becomes very important to support students in engaging with these science practices. Much of what is taken away from these virtual labs will come from teacher design around the virtual labs. Many of the crosscutting concepts are implicitly stated in the labs used in this school. This is a concern because the NGSS emphasizes that these concepts need to be made explicit for the students (Quinn et al., 2012). A total of six of the seven crosscutting concepts are, at least implicitly, stated in the labs.

In terms of constructivist design supports the labs reached some common supports like having descriptive sequences, distributed learning supports, controlling of confounding variables, learning content to solve a problem, limiting the lab to one screen, and virtually manipulating the materials rather than watching simulations. The gaps that many of these labs missed were providing scaffolds (with the exception of the blood typing lab) and providing an ill-structured problem with support (except for the blood typing lab). These labs were unable to support communication or interactions with peers to build a deeper understanding of the content. All of the labs did not for direct interaction with the lab in terms of stating understanding or what prior knowledge the students will come with.

The emerging categories that came as a result of these labs were having videos embedded into the labs, having an engaging introduction, giving students’ information on the equipment they are using, connecting them to the larger scientific community, and allowing for multiple
navigation within the lab. Connecting to the larger community is especially important when viewed from the perspective of authentic activities (Edelson & Reiser, 2006) as students are participating in similar cognitive tasks that experts are also using in their careers.

**Cyber Charter School C Case Study**

**Lab 1 – Soil horizons lab.** This lab intends for the students learn the process of soil formation and what the different types of soil are. The standards intended for learning through this lab are listed at the bottom of the instruction page. It is stressed that there are unlimited attempts to complete this assignment. The lab requires a link to start the lab. If the link is not right clicked it opens in the same tab as the LMS and the window to the LMS is lost... There is no announcement in the LMS that this is a lab and the assignment completed is known as a quiz. Once an assignment is begun there is one day to finish that assignment. Figure 4.46 shows the introduction to the soil lab.
Figure 4.46. The beginning of the quiz shows students the opening lab page and how they can interact with it.

The directions encourage completion of the activity on soil formation in both cold and warm conditions. There are instructions to read the pop-up window that appears. These pop-up windows show how different factors like water and temperature impact soil formation. The lab can be directly interacted with through the course window. Once the cold or warm button is clicked the soil formation simulation begins. There is a description given of what is happening in each step of the soil formation process. There is nothing in the design of the lab that shows that the text in the pop-up box changes depending on what they are watching. There is no reverse
navigation in the lab once the soil formation process has begun. Figure 4.47 shows how soil forms under cold conditions.

**Figure 4.47.** The simulation of soil formation under cold conditions.

The continue button on the left hand side of the simulation is clicked four times to watch the process of soil formation. There is no of independence or ill-structured problem-solving in this lab as the lab completes the activity and there are no variables to control. If technology or accessibility prevents viewing the simulated tutorial the LMS presents a picture process of soil formation. This presents the lab in multiple perspectives depending on the technology capabilities of the student. For example, if a student had dial-up or issue that prevented loading the simulation they could view the picture showing the process of soil formation. Figure 4.48 shows the screenshots that can be looked at in lieu of, or in support of, the lab.
Figure 4.48. Screenshot of soil formation.

Six questions need to be answered with respect to the simulation. These questions look at the process and identify cause and effect of soil formation as well as what material various horizons are composed of. When the cold and warm simulations are run there is no difference in actions of the simulation. The descriptions of what happens in soil formation are the same for the warm or cold variables and none of the questions are about considering the difference between these two temperatures with regards to soil formation. It is thus unclear why the lab asks to run the experiment under cold and warm conditions if no differences are apparent.

When the six multiple choice questions are completed the lab is able to be submitted, and the lab automatically grades the answers. Students would be given their grade immediately and be able to see what they got right and wrong. Figure 4.49 shows what this immediate feedback looks like.
**Figure 4.49.** Immediate feedback from the soil horizons lab.

In this lab there is a simulation of soil formation to watch but not expectations to engage in science practices. The descriptive sequence is confusing because the instructions give a hyperlink to the lab but the lab can be observed from within the LMS. The lab takes advantage of reducing the time and showing previously unobservable phenomena to students (de Jong et al., 2013). The problems to solve in the lab are well-structured and there are no scaffolds built-in to help structure the students thinking (Jonassen, 1999; Pea, 2004; Puntambekar & Hubscher, 2005). To solve the problem in this lab there is no requirement to learn the content (Jonassen, 1999).

**Lab 2 – Energy skate park lab.** This lab uses a PhET simulation to “experiment with the different states of matter” (directions). The learning goals for this lab are to observe potential and kinetic energy, observe how different masses effect energy, and “experiment with different levels of energy” (directions). The lab requires a worksheet to be downloaded to help guide the experiment. The descriptive sequence for this lab is confusing because there is a button to click to download the worksheet but there is not a link to open the lab as can be seen in the Figure 4.50.
Figure 4.50. Skate park lab directions. No link to actual lab.

To access the lab the teacher was referring to requires opening the worksheet and clicking on the active link in the worksheet. This expands the number of windows that need to be interacted with. The worksheet gives instructions for how to set-up the equipment for the lab and then has data charts for to complete that will help to answer questions about the lab. The lab simulation without manipulating the set-up can be seen in Figure 4.51. There are many different options to change on the right side of the simulation but the lab is open in that there is no direct instruction or scaffolding to interact with. The worksheet does not give instruction to interact with the lab before beginning the directions for the experiment for the class. However, the lab allows for the changing of variables like the height of the ramp and the gravity level while at the same time inserting many different tools to physically observe the changes in energy. This helps to make visible processes that are invisible. Figure 4.51 shows how the lab is set-up.
Figure 4.51. Set-up of the energy skate park lab.

The directions require the set-up of the skate ramp to be the same as the picture in the worksheet. The lab allows for a different type of skater and the worksheet follow the same procedures with different skaters. This controls the confounding variables (Chen & Klahr, 1999) and removes the control and independence from the student (Vrasidas, 2000). To get the design of the simulation set-up as instructed in the worksheets the simulation needs to be paused to reposition the skater at the top of the ramp. When the skater is repositioned at the top of the ramp he can fly off of the ramp or fall if not positioned correctly. The lab does not have prompts to consider this experimental design error or that this is a possibility. The directions imply that as
long as the skate park is set-up like the picture in the worksheet it will work and the data will be collected properly. Figure 4.52 shows these directions to set-up the lab.

Name: ____________________________________________

**Energy Skate Park**

Go to -
https://phet.colorado.edu/en/simulation/legacy/energy-skate-park

Create a ramp like the one shown that is 10 metres tall. Make sure the ramp does not touch the ground.

Drop the skater from the top of the ramp so that he reaches the top of the ramp on the other side and comes back again.

Open the ‘Energy vs. Position’ graph and wait until a full set of data has been collected. Use this graph to fill in the information in the table below.

*Figure 4.52. Directions to set-up the lab. Does not take experimental error into account or give students tips/scaffolds for if the skater does not move as described.*

The lab does not have any scaffolds or guides that appear if the set-up is not designed correctly. For the experiment to be correctly run to fill in the graph it must be zoomed out to the right scale and have only kinetic and potential energy selected. The directions say that this lab can be stopped after a cycle of data is completed but what is meant by a cycle is not clear nor is an image provided of what one of these cycles looks like in the worksheet that accompanies the lab. These same procedures are completed for four different skater types. The chart or the directions do not direct attention to the mass of these different skaters. *Figure 4.53 shows what I interpreted to be one cycle of data.*
Figure 4.53. Graph of the original skater’s potential and kinetic energy.

The students are required to answer questions on the worksheet to complete the lab. These questions do not require interaction with the simulation to answer them. The questions ask to answer observations from the data. The last question requires explanation from the data points about why when the kinetic and potential energy change the total energy remains flat. The worksheet specifies at the bottom of the first page that the assignment is completed. If students would want to earn an ‘A’ when they complete the lab two screenshots need to be attached to the lab but it does not state what two screenshots.

This lab offer extra credit if the skate park can be set-up in a straight line as shown in Figure 4.54. In this part of the lab energy is recorded according to starting location rather than mass. There are cause-and-effect questions to answer based on the position of the skater that ask
to explain why actions happened from the data. The worksheet provides a hint that the kinetic energy change was not due to the height of the skater. The directions are unclear as to how to set-up the ramp as seen Figure 4.54. The original ramp only has three blue points on it and the lab or the directions do not show how to get more than three points on the ramp.

WANTA GO FOR THE GOLD!! CONTINUE...
**IF YOU WOULD LIKE TO CONTINUE, YOU MAY AND SUBMIT FOR EXTRA CREDIT POINTS!

Set up your ramp so that it looks like the one shown.

Drop the skater from each of the dots on the ramp, starting from the top, and complete the table below.

Figure 4.54. Directions for the extra credit in the skate park lab.

The lab then has another for extra credit by completing an additional simulation. Each simulation gets increasingly complex and has multiple variables being explored in the lab. In the final simulation instructions the skate ramp is set-up and then the lab looks at the potential energy on different planets with different levels of gravity. This simulation builds on the first two labs and now variables are manipulated and it requires for understanding of cause-and-effect from more than one variable. Figure 4.55 shows this final simulation and the data that needs to be collected.
Set up your ramp so that it looks like the one shown.

In the table below record the **maximum potential energy** for each of the skaters at the top of the loop. Repeat this on the Moon, and on Jupiter. You will need to place the skater at the top of the ramp each time you change location.

<table>
<thead>
<tr>
<th></th>
<th>PhET Skater</th>
<th>Star Skater</th>
<th>Bulldog</th>
<th>Bug</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jupiter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 4.55. The set-up and data tables to record for the final activity.*

This lab has a worksheet to help guide through the PhET activity. Without this worksheet the lab would be open-ended with no scaffolding or directions on how to manipulate the lab. This lab is an ill-structured problem-solving environment (Jonassen, 1999) but runs the risk of being constructivist without guidance (Mayer, 2004). The deep learning potential advocated by Sawyer (2006) in a constructivist environment has ill-structured problem solving with supports, feedback, and tools to help amplify thinking. This lab had supports in the form of sense-making scaffolds and descriptive text that was unclear on how to set-up the labs. In addition, the labs gave no personalized feedback.

There were some science practices present such as collecting and analyzing data and constructing explanations but were missing features to support the following science practices: research question formation, engage in argumentation, or communicate information. Cause-and-effect as a crosscutting concept was made explicit in this lab, but others such as stability and change were implicit throughout the lab. Quinn et al. (2012) stress the need to make these
crosscutting concepts explicit. Cause-and-effect became increasingly implicit as it built on prior iterations of the simulation.

**Lab 3 – Matter changing states.** This lab is titled a virtual investigation. When the entry point to the lab is clicked on it specifies that there are two attempts to successfully complete this lab. On the left hand site of the lab is a ‘quiz’ navigation window. This is confusing because it is titled a virtual investigation at one part of the lab and a quiz in the other part. The descriptive text of the lab could have been made clearer (Wettstein, 1978). Figure 4.56 shows the directions for this part of the lab.

*Figure 4.56. Directions for the matter changing states lab.*

The first step of the lab is to open up the software that will be used to complete this lab. There are very clear and ‘text-lite’ directions with images that have directions over the image to give guidance as to how to set-up the lab. The lab that will be used is the PhET simulation. This lab opens up in a new window. The lab is open and allows for ill-structured experimentation, but the teacher has directly embedded this lab into the LMS with accompanying directions. The initial set-up of the lab is seen in Figure 4.57.
The introduction to the PhET lab.

The lab is structured as a series of questions to answer. This provides a series of steps to focus on and helps to focus thinking on the important features of the lab. The lab questions are structured with informal assessments built-in to make sure that the experiment is being set-up correctly and how to prepare for the next part of the experiment. There are instructions for which variables to focus on, but the expectation is to explore the simulation and make initial observations before proceeding with the lab. This design will allow for the lab to address multiple student explanations at the beginning of the lab. A data table needs to be completed for neon to make observations about the element in a variety of different states. However, the directions for the table are not clear in terms of how to describe the space between atoms or attraction between the atoms. Some of the graph is a clear number or description from the
simulation and others are more subjective readings. This descriptive sequence could be confusing to students (Wettstein, 1979). The teacher prompts and scaffolds the lab to arrive at the intended outcomes of coming up with rules based on the data and observations they have used to make sense of the lab. This lab has sense-making prompts that use science practices to help structure and guide thinking about the lab (Quintana et al., 2004, Sandoval & Reiser, 2006).

The data tables needs to be completed for neon, water, and oxygen. These multiple observations allow for generating a rule based on those observations. This is allowing for learning content through experimentation with the lab (Jonassen, 1999; Quinn et al., 2012). Figure 4.58 shows what neon looks like in a gaseous state.

Figure 4.58. An example of neon in a gaseous state. Temperate can be altered to look at movement.
When the experiment is run with the three scenarios and molecules and the rule for temperature changes and element motion is established the lab is complete. The lab can then be submitted and the window that pops-up confirms that the lab has been submitted. This lab does not require questions based on observations, engaging in argument from evidence, or communicating results from science practices.

In addition, the lab prompts make explicit the relationship, or cause-and-effect between actions and the behavior of the molecules. However, the other crosscutting concepts such as patterns or changes in energy and matter can be implicitly understood from the lab. To have these be explicit, the lab could show embedded videos of what the molecules look like in real life with narration rather than through modeling of the balls without explanations or scaffolds.

**Lab 4 – Will it fossilize?** This lab is categorized as homework. The learning objectives for the lab are to learn what different conditions are needed for a fossil from the dinosaur era to form correctly. This lab comes from the Winterville Web site and the lab is able to be displayed in English or French. The lab is introduced through the directions seen in Figure 4.59. There are multiple attempts to complete the lab but once the first attempt is started the lab must be completed in 24 hours. The LMS provides a summary of any previous attempts on the lab and that evaluation will occur based on the best grade for that particular student. A different Web site needs to be opened to complete the lab and when it is clicked on it opens in the same window as the LMS and the LMS is lost. This is not the best practice for opening external websites from a page. Figure 4.59 shows the directions for the lab.
Directions for the fossil lab.

When the lab is interacted with a text box can open on the right hand side of the screen that gives information on the science behind the lab. This information provided discusses fossilization and who uses fossils in their work. After the reading of science content the lab returns to the simulation. There is a social media element to this lab as students could share the simulation with their friends through different social media accounts and also “yeah” the game. This “yeah” feature is similar to a like on Facebook. Although this is called a game by the website, similar to the blood typing website from Cyber Charter School B, lab has many game-design features in it. This lab is ill-structured as students could experiment and fail as many times to see what conditions need to be made to make a fossil and the different types of fossils that could be made... The lab offers a choice to be guided through the introduction to the lab through a learning support or to skip the intro to the lab entirely as can be seen in Figure 4.60.
The introduction to the fossil lab.

The teacher includes screenshots to the lab in their homework instructions. These instructions are implicit in saying that it is okay to fail many times in trying to create the right conditions for a fossil to form. It is not easy to get the right conditions of variables and I got frustrated when I was not forming the fossil correctly and it was not supported that there would be failure. The lab gives students power in deciding how to interact with the lab and a level of independence with the lab (Vrasidas, 2000). At the same time, the teacher scaffolds the lab
through the choices that needs to be made to answer the first question of which variables for fossil formation. To work through one of three options needs to be selected for each condition that affects the process of fossilization and then the fossilizing process can begin. Figure 4.61 shows the set-up to begin trying to make a fossil.

![Figure 4.61. Fossilizing process with specified conditions](image)

As the lab goes through the process it very quickly shows the different time periods of the dinosaurs which shows an explicit reduction in the time it would take to conduct that experiment. If conditions are not favorable the combination will not make a fossil because the bones were consumed by animals. However, the lab does not specify why this combination of variables led to scavengers eating the bones in the explanations. The next question in the lab is much more exploratory in its design and only specifies that accidental needs to be chosen as the mode of
exposure. There is not scaffolding in the lab to give them hints to try different combination of variables. It is an open-ended environment with minimal automatic guidance. However, it is not open-ended for manipulation of equipment that would be used to unearth fossils in nature. In fact, there is no mention of the equipment and the simulation is run through a time capsule. This is not authentic of showing how fossils would be discerned in the real-world. Figure 4.62 shows an example of failure in making a fossil.

Figure 4.62. I failed to make a fossil with these conditions

When each of the three options for each condition is scrolled over for each variable such as ‘mode of death’ it explains if these conditions would or would not be favorable for fossils. A multiple choice answer needs to be selected to answer this open-ended exploration of fossils with humans discovering them. The answer is verbatim the response that comes from the lab when it
has human error as the reason a fossil was not formed. The crosscutting concepts are not explicitly stated in the lab. Through the simulation the crosscutting concepts of patterns and cause-and-effect but this is only implicit.

The teacher guided worksheet asks what conditions failed to make a fossil and why. The text with the questions tells how many points each question is worth. The online worksheet can be directly typed into to answer the questions in the lab. However, this does not explicitly for research questions around the best conditions for a fossil or the authentic procedures that scientists would go through when discovering and analyzing a fossil. The final activity of the lab is to come up with a successful combination of conditions that would produce a fossil. After this is done the lab informs that the student has discovered conditions that will produce a fossil but does not show what kind of fossil it could be or why those were good conditions to produce a fossil. The lab asks for reflection on what conditions were unfavorable to make a fossil and which were favorable but does not scaffold to think about why students would know this or help them make sense of the complex process of fossilization. In addition, there are no prompts supporting communicating results or engaging in argument from evidence. The descriptive sequences are present within the lab but are not tailored to help understand the lab. For example, there is an introduction to the lab and the science behind the lab is included in the introduction. This information needs to be looked at before problem solving or applying content to solve the problem. This is not the process that Jonassen (1999) refers to in best practice for ill-structured problem solving or that Quinn et al. (2012) suggests when tying together the science practices, crosscutting concepts, and core ideas. A lab should be designed to learn content through the lab rather than applying content previously learned.
Summary Cyber Charter School C

The labs from Cyber Charter School C are categorized as quizzes or assignments within the students LMS. There are time limits on various labs at the entry page to that lab. For the most part, the time limit was 24 hours. The labs are pulled from different Web sites or programs such as PhET or Pearson and are all open resources. The labs do not involve the parent or any communication prompt to discuss what was found in the lab. Two of the labs used are classified as simulations while the other two are experiments that require students to set-up some of the equipment. The descriptives from the worksheets/LMS are not always clear. For example, in Lab 1: Soil Horizons the lab states to open the lab in a separate window. However, the lab can be completed from within the LMS and there is no need to leave the LMS.

All of the labs selected are completely virtual and require students to answer questions created by their teacher after they complete the lab. 75% of these labs had prompts for students to reflect/amplify their thinking when they complete the lab and thus were classified as cognitive tools (Jonassen et al., 1998). 50% of the labs had features of ill and well-structured problem solving within the lab. Both of the labs were PhET labs that had ill-structured problem-solving. Embedding the labs within the LMS turned the ill-structured environment into a well-structured environment will less independence. There were scaffolds present in all of the labs that had ill-structured problems. This is important for helping to support problem-solving (Chin & Chia, 2005, Jonassen, 1999).

All of the labs studied from this school do not have any science practice markers in asking questions, engaging in argument, or communicating results. All of the labs used models, but only the skate park lab required development of the model to represent the phenomenon. The work associated with the labs required planning investigations but not looking at the results of
the experiments/manipulations. For example, all of assessment questions focused on specific parts of the lab but not on what the data was telling them about the phenomenon or how to make sense of the experiment.

The vast majority of crosscutting concepts identified in the labs were implicit. The only crosscutting concept that was made explicit was cause-and-effect in 75% of the labs. For example, in the soil simulation the lab was designed to focus attention on what is causing the soil to change into different horizons. Scale, proportion, and quantity, and structure and function were not identified in any of the labs from Cyber Charter School C. While other crosscutting concepts were identified the underlying concept that was impacting phenomenon or results in the lab was not made explicit. In the skate park lab the student would need to identify the kinetic and potential energy but the questions asked were not about reflected on the relationship between energy and matter, for example.

**Cyber Charter School D Case Study**

**Lab 1 – Virtual microscope lab.** The learning objectives for this lab are very clearly marked at the top of the lab page. The learning objectives are to learn about how microscopes are used in different fields, and how a microscope is adjusted, focused, and used through interaction with a virtual microscope. The microscope is an open tool from the University of Delaware. In this lab everything is on the same page except for the microscope simulation and the pages from the textbook that explain the use of microscopes. The structure of the lab begins with a lesson introducing what microscopes are used for and what the parts of the microscope are. This lab is different than all of the other labs analyzed because it focuses specifically on learning how to use a scientific tool. Learning how to use tools to experiment with the physical world is an important laboratory component (Singer et al., 2005). Figure 4.63 shows the introduction to this lab.
Figure 4.63. Introduction to the microscope mini lab

The lab fills in any prior knowledge that would be required before beginning the lab. This introduction will not be covered because it is not an actual part of the lab but it guides and focuses on the content of the structure and function of a microscope before they begin the virtual lab. The lab shows pictures of specimens under the microscope and allows for visually seeing patterns not visible to the naked eye. Figure 4.64 is part of the preparation to learn the parts of the microscope so that the student would be able to manipulate the equipment. At this point in the lab, the script is very descriptive and does not give control or independence.
The lab is ready to begin and it asks for opening a link that goes to a virtual microscope simulation from the University of Delaware. As the virtual lab is completed a worksheet needs to be filled out. There are distributed learning supports and scaffolding within the theoretical ZPD of the student based on the introduction information provided in the lab. There are a significant amount of technology tools to support work in this lab. For example, when the lab worksheet is completed it can be self-checked to see if there is a wrong answer. There are very clear directions for how to set-up the microscope and a model for which to draw the slides seen. Figure 4.65 is the model for how the images seen should be drawn in the worksheet.
Figure 4.65. Model for students on how they are supposed to draw what they see in the microscope.

The lab does not ask for a hypothesis on what the slides will look like under different magnifications. There is also nothing in the worksheets to see the complexity of working with a microscope and common issues that may happen when working with a microscope. However, this lab is very authentic in including all of the parts that are on an actual light microscope. The introduction to the microscope includes audio that explains how to get the microscope into focus and a checklist to make sure the microscope is prepared appropriately to look at specimen samples. The supports to guide eliminates independence in setting-up the microscope but is teaching the basic ways of preparing a microscope as is needed for the learning objectives of this experiment. As the tasks to complete the checklist are done, the checklist automatically gets filled in. This could help students to monitor their work and reduces unnecessary cognitive load.
while learning about how to manipulate the microscope. Figure 4.66 shows the image that accompanies the narration for setting-up the virtual microscope.

Figure 4.66. The narration tells students the difference between a real microscope and how this lab works. For example, it shows the slide clip moving but states that students do not need to do that in the virtual lab.

The microscope can be manipulated without listening to the tour. The tour can then be listened to if one is unsure of how to set-up the microscope or the entire microscope can be set-up without listening to the tour. The worksheet that accompanies the lab includes similar directions in text format. There are multiple modalities through which to view the content: audio, text, and visual. This is important for giving ample opportunities to learn the content and procedures to increase the likelihood for longer term retention of material and procedures (Halpern & Hakel, 2003). The worksheet prompts to set-up the lab correctly and then draw both the cheek and onion root tip slides. There is no hypothesizing, communicating, or arguing from evidence, but the lab does require computational thinking and modeling to show what is being
seen in the microscope. In addition, crosscutting concepts like patterns and proportions and quantities are explicitly explored. There is a guided script and distributed learning supports that help to reflect thinking about what scientists use microscopes for. The confounding variables are somewhat controlled by the script. However, when setting up the microscope the lab allows failure when working through the checklist. From personal experience, I know that several students think that they see something on the microscope when in fact it is not the image they are supposed to see. This lab is very similar to looking at actual slides as that image is also presented to the students in Figure 4.67. This is frequently the same image that is thought to be a specimen in physical labs.

*Figure 4.67. The image that many students see and think is what they are supposed to be seeing through the microscope*

After the image is in focus, the microscope can be adjusted to a different magnification and then the microscope needs to be refocused for that magnification. There are scaffolds to
refocus through modeling and fading in the checkmarks on the left hand side of the lab. The lab provides measurements in the middle of the slide to help them see the scale and proportion of various items in the microscope. Figure 4.68 provides the image to show how big the drawings should be. The worksheet stresses that if required the entirety of the worksheet can be taken up for the drawings.

Figure 4.68. Modeling the drawing using the letter ‘e’ slide

After the check cell lab images are completed, the lab prompts to draw the onion tip without any instruction aside from the checklist. This is an example of fading scaffolding in the ZPD because the lab helps to work through the first slide but not the second using the same techniques... The lab has many self-check stop points to check for understanding in terms of actions and processes... These scaffolds lead the students from a well-structured to ill-structured
environment, but does not assess if this transition from well-structured to ill-structured is taking place at the right time. This lab is particularly absent on many features of science practice but focuses heavily on a few such as modeling and computational thinking. Considering the learning objective for the lab is to learn how to use a microscope rather than answer specific questions about the microscope this makes sense. However, the lab could have had hypothesizing/predicting about differences between the slides of the animal or plant cell.

**Lab 2 – Mixtures mini-lab.** This lab works with the concept of mixing materials. The lab starts with the standards and objectives that are designed to be met by completing the lab. This lab also has details at the top of the introduction that the goal is to be able to explain the difference in different kinds of mixtures and how to separate the mixture back into its individual parts. Figure 4.69 shows the objectives, standards, and the essential question of the lab.

![Figure 4.69. Introduction to standards and the learning goals of the lab](image-url)
The lab introduces mixtures through everyday items that are familiar such as soil. The difference between soil samples is illustrated with looking at different types such as soil, sand, water with soil in it, and clay. The lab is very picture heavy and ‘text-lite’ in the descriptive text to illustrate what the mixture looks like. The audio allows for important terms and definitions to be heard. The lab consists of an extremely large amount of pre-lab information without asking for feedback or interaction. Once the lab starts, it gives a hypothetical situation in the worksheet to predict about how a mixture would be separated back into its parts. After this hypothetical experiment is thought through and the worksheet is completed the lab can begin. Figure 4.70 shows how students can use the tool to figure out the material, processes, and technique to separate the mixture.

*Figure 4.70. Image of the lab used for this experiment.*
One potential issue with this virtual lab is that it does not work in Google Chrome. This is the first time this issue has been encountered but it is something to think about from an accessibility and access perspective. The lab directions tell what is going to be done in the lab poses some questions without expecting a response and highlights use of the help option if it is not clear how to separate a mixture with specific tools and processes. The lab introduces the crosscutting concept of structure and function through the way the data table is labeled with mixture, separation mechanism, and physical materials that allow separation. The LMS allows for skipping all of the guided instruction but there is navigation there to guide and scaffold students if they get stuck when they would complete the lab. When working through the lab if the wrong mechanism or physical property is chosen when separating the mixture the scaffolding prompt in the top left corner change the text and guides towards selecting another answer. Work can be automatically saved while completing the virtual lab through the use of a program called TACCK. Figure 4.71 shows what happens when the wrong mechanism or property of the mixture is chosen.
Figure 4.71. Example of what happens when the wrong separation mixture is chosen.

When the lab is finished there is no reflection, analysis, or conclusion in the actual lab. The assessment taken helps to guide thinking through asking questions about what was enjoyable while completing the lab. Figure 4.72 is the worksheet shown as the lab is completed. Figure 4.73 shows immediate feedback in the form of green or red highlights in the worksheet. The color selection does not take into account accessibility for students who may be color blind.
Figure 4.72. Worksheet completed along with the lab

Figure 4.73. Full credit for a worksheet cannot be received for multiple attempts but partial credit can. Green means correct and red means incorrect.

Lab 3 – Osmosis. This lab is intended to teach about osmosis after the class learns about the cellular membrane... The standards and objectives are outlined at the top of this lab. The learning goals for the lab are introduced and key audio can be played to learn about important vocabulary in the lab. Figure 4.74 shows the introduction to the lab.
The introduction to the lab has an embedded video to illustrate osmosis. This video helps to relate the concept of osmosis to a concept that would be observed in everyday life and take away information in short bursts (Hisan & Cigas, 2013). Figure 4.75 shows the instructions for viewing this video.
Now, I would like for you to watch this video. This video demonstrates the concept of osmosis using lettuce.

*Figure 4.75. Video in the beginning of the lab.*

The lab allows for playing interactions while reading text and this presents the information in multiple formats for students to learn from. There is an additional virtual lab that could be completed from Glencoe Hill on osmosis but this activity is not required and will not be analyzed as it is not the primary lab the teacher selected.

The lab activity that is completed for this lab is watching a YouTube of the ‘naked egg’ lab to learn about osmosis. The YouTube video is viewed and then questions need to be answered that are embedded directly below the video in a TACKK lesson. The lab video goes over what they will be doing in the experiment, the equipment needed for this experiment, and the goal of the lab. The video zooms in on what is happening in the egg and speeds the process so that the egg shell dissolving can be viewed in real time... The video directly what is done in
this experiment and what is included in every step of the procedure. The video does not prompt for what might happen or give time to hypothesize at the beginning of the lab. In addition there are not reflection or scaffolding prompts between the steps of the video. At the end of the video the chemistry behind this experiment is illustrated to show what is being done in this experiment. This is simplified because the structure of water is shown but the structure of the content in the egg such as sugar is represented through a circle with the word sugar on it. This helps to reduce the cognitive load by focusing attention on important parts for understanding, known as selective attention. (Sweller, Jeroen, Merrienboer, & Pass, 1998). The video can be viewed from the following link: https://youtu.be/SrON0nEEWmo. The video can be played from the lab. However, there are not intentional pauses built into the lab where reflection, problem-solving, or conjecturing could take place. Figure 4.76 shows the egg dissolving in vinegar and Figure 4.77 shows how different the egg looks after being in two different mediums.
Figure 4.76. The egg dissolving in vinegar

Figure 4.77. Showing the difference and the change in the egg that was in vinegar and corn syrup

The data table is filled because it is impossible to see from the video what the mass change of the egg was in the different solutions. This data table has the values and observations automatically entered. Questions are answered based on what was observed in the video and analysis questions. The lab has been a simulation to this point as all that has happened is observation without manipulating equipment.
These questions revolve around explaining the purpose in the experiment and then some hypothetical and conceptual questions requiring articulation of what is seen in the video. The lab does not have descriptives to this point to show how to work with the video, data table, and questions all at the same time but does have a descriptive that questions need to be answered in the LMS rather than in the window seen in Figure 4.78 which gives to separate screens to manage.
Figure 4.78. Questions students are asked after they watch the video on the naked egg

The lab does not prompt for communicating results and in these questions there are no scaffolds nor is there immediate feedback as everything is a short answer question that requires personal evaluation. The lab does not require asking questions or designing an experiment but
the worksheet questions require explanation from a data table and implicitly focuses on certain crosscutting concepts such as stability and change.

**Lab 4 – Gummy bear diffusion and osmosis lab.** The goal of this lab is to learn about diffusion and osmosis through gummy bears. There are text-heavy directions for what diffusion and osmosis is and what students will be doing in the lab. The standards and objectives are identified at the top of the lab. Figure 4.79 shows the introduction to the lab.

*Figure 4.79. Introduction to the gummy bear diffusion and osmosis virtual lab*

This lab uses computational thinking with the determining volume through LxWxH, requires a student created hypothesis, and collects measurements that produce an automatic graph to visually represent data collected. In the lab there are many reminders to contact the teacher if there are any questions. Figure 4.80 shows the instructions for the lab.
Figure 4.80. Instructions for what students will be doing in the labs

This lab takes place in three different days to look at the mass of gummy bears and then analyze that data. The lab does not require the experiment to be designed or to collect data about the mass of the gummy bears but does require making observations and reflections from the experiment. There is scaffolding to build the hypothesis through a quiz that allows for multiple attempts. The procedures are provided and there are limited outcomes that can result from this lab. When the lab is being completed it allows for zooming in on a gummy bear to determine the measurement for entering the correct volume. In Figure 4.81 students enter the measurement into the white box. If it is wrong the box highlights red. After this measurement is entered it
requires going to the graphing window and the graph will auto-populate the right color to represent that measurement. This helps to control extraneous variables and does not rely on students graph-making abilities to control for creating a correct graph. Figure 4.81 shows the data table that needs to be filled in.

Figure 4.81. The data tables were students fill in their information

The same steps need to be completed for the other parts of the lab but the gummy bears are submerged in different liquids. The initial weight, the weight after being in distilled water, and the weight after being in salt water need to be recorded. Each gummy bear can be clicked on, the volume recorded using the question, and then enter the numbers in the graph and watch the graph auto populate. Figure 4.82 is of the graph created from the data tables. Figure 4.83 shows what the graph looks like after one set of measurements is entered.
Figure 4.82. The graph fills in as numbers are entered.

Figure 4.83. Example of how the graph looks after entering mass for the blue gummy bear.

These steps are repeated for each color graph allows for seeing if the color affects how much volume the gummy bear gains in each liquid. There are descriptives throughout the lab as learning supports to remind the student that when they complete the lab they must enter the mass
of the gummy bears in the graphing software. This is important as the graph is in a separate window and not connected to the LMS. Figure 4.84 shows example of the clear gummy bears being measured.

![Graph showing measurements of gummy bears](image1)

**Figure 4.84.** Example of clear gummy bear being measured

When all of the measurements are completed the graph is completed and illustrated in Figure 4.85. Figure 4.86 shows the box where the finished graph needs to be uploaded to in the LMS.

![Graph showing gummy bear diffusion and osmosis volumes](image2)
Figure 4.85. The completed graph for each gummy bear

Figure 4.86. The upload box in the LMS for students to submit their graph.

After the graph is completed there are analysis questions to answer about the lab. These can be seen in Figure 4.87. The analysis questions require use of the graph and measurements to infer differences and changes between the gummy bears. However, the analysis is all multiple choice so there are no explanations required, engaging in argument from evidence, or communicating results. These are all features fundamental to science practices and inquiry. This lab is good at responding to user actions and offer immediate feedback in the form of a self-check (Jonassen, 1999). Figure 4.87 shows the final analysis.
Figure 4.87. Final analysis for the gummy bear lab

After the lab is analyzed there are some concluding questions that ask for reflection on what has been learned and answer questions based on what happened in the lab. Results need to be explained but not argued or communicated. Figure 4.88 shows the conclusion questions for the lab.
Summary for Cyber Charter School D

The labs used in this school focus heavily on cellular processes for life science concepts. The labs have a lot of supports built in including immediate feedback, multiple revision attempts, and software that reduces the cognitive load. The labs meet five of the eight science practices but does not allow for asking research questions, engage in argument from evidence, or communicate results. The labs are especially strong at supporting mathematics and interpreting data and weaker in allowing for model development or planning investigations.

For the crosscutting concepts, the labs do not support systems or system models. Patterns, cause-and-effect, and structure and function are explicitly supported while stability and change is implied in the labs. The design of the labs that help to make these explicit was the teacher instruction built into the lab to help focus attention.
The constructivist design components revolved around scaffolding and supporting learning but did not allow for communicating or asking about prior knowledge before the lab is started. The material was always presented for from more than one perspective. The problems were also well-structured much of the time without room for error or experimentation within the labs. An exception to this was the microscope lab which allowed for experimenting without intervention and using the instructions if needed. Most of the labs (75%) were simulations and with some manipulation of materials. Similar too many of the other labs and schools studied none of the labs scaffolded to reflect on experimental design or emphasize the complexity of empirical work (only one lab did this). The emergent categories that came from this lab were having the same introduction to all the labs that included standards, learning objectives, an engaging introduction for, and limited browser compatibility.

**Cyber Charter School E**

**Lab 1: 1.04 Understanding the scientific method.** This lab is intended to understand the scientific method. The lab defines the scientific method steps and discusses controls and variables. At no point during the lab does it ask for prior knowledge about experiments or controlling variables in experiments. The lab includes a description of what the types of experiments are but does not ask for reflection on these ideas or make sense of what is being presented. The text describing the lab does not provide an opportunity for ill-structured or multiple explanations. The following text illustrates this:

> I wonder what would happen if we compared how a feather and a bell fell in a vacuum? If we sealed off the leaning tower of Pisa and removed all the air, I bet it would work. Wow! Modern technology is great.

> When completing the virtual lab there are directions for how to work with the simulation. The lab allows for experimentation and then looks at the clipboard to see how to record data
from the simulation. This lab can be considered a virtual lab and not a simulation because while there are decision on what mode to put the experiment in but it does not give independence in control of the script. While this could be seen as a limited experiment, this is the only set-up in the entirety of the lab in which the lab design does not maintain control. The lab does not have feedback when the simulation is being manipulated. The lab tells what a hypothesis is and the procedures for the lab but does not require creation or reflection on individual student hypotheses. The lab tells why the generated hypothesis was incorrect but does not ask for thoughts on this or scaffold them in actively constructing knowledge around the ideas behind the lab. The lab helps with carrying out an investigation and reaches more crosscutting concepts such as cause-and-effect and systems.

After the lab an assignment needs to be completed about the lab. This requires going to a different section of the LMS and leave the lab in which they were involved and construing meaning from. This assessment is a multiple choice quiz that asks about the content that was covered in the lab and other information in the module the lab was placed in. Figure 4.89 shows the objectives for the lab and the image for the lab. Figure 4.90 shows this image magnified.
Objectives

In this lesson, you will complete the following tasks:

- review the steps in the scientific method
- practice the steps of the scientific method by completing an online activity

The Scientific Method

Italy has many wonderful places and some really cool historical attractions. One attraction is pretty famous! Many historians believe that the leaning tower of Pisa is the place where Galileo Galilei, an Italian scientist, conducted his famous cannonball experiment. The experiment showed that the rate at which an object fell did not depend on its weight. It has been recorded that Galileo dropped two cannonballs of different weights off the tower and they fell to the ground at the same speed.

Let's look at this experiment to show the steps of the scientific method. Let's move to the lesson page to continue our Italian adventure!

Figure 4.89. In this lab students learn about the scientific method through a virtual lab.

Figure 4.90. This is the simulation with which the students interact for this virtual lab.
**Lab 2: 6.03. Limiting factors in populations.** The learning objectives for this lab are to learn about limiting factors and how they may affect a population. This unit was selected as a lab because it has interaction with a map and taking the knowledge learned from the map into the local home environment of students to look at population control/growth/diversity. The lab does engage with science practices and crosscutting concepts although it is a simulation and not an experiment according to how they are defined in this study (Crippen et al., 2012). Students are introduced to what it means to have limiting factors to population diversity by looking at global extreme environments. The virtual tour provides students with pictures and a description of each environment. These examples provide a concrete way to think about limiting factors. For example, the lab introduces food as a limiting factor by showing a greater diversity of birds where there is more food. However, the lab does not ask to identify that limiting factor from the tour nor to hypothesize about what the limiting factor could be before illustrating this for them. The more intensive experimentation for this lab comes when requiring exploring plants and animals in their hometown. The procedures are to “examine the animals and plants that live around your home, choose one kind of plant or animal that lives there… identify the limiting factors as a biotic or abiotic factor.” However, if students would be in need of more help with limiting factors the lab requires them to leave this page and go to the first page of the lesson where an organizer can help them to understand this. The graphics organizer does not scaffold to examine local animals and plants. This is an ambiguous task without guidance for how to effectively do this while maximizing their independence in the lab. In other words, it is an open-ended inquiry environment that fulfills the criticism of constructivist learning environments (Kirschner et al., 2006).
After the lab there is a worksheet that needs to be completed. This worksheet has students identify the limiting factors, if they are biotic/abiotic and how the student would think that this limits population growth. However, it does not ask for hypothesizing or reflecting on what they think would be the factors for population growth. It does have students infer from what they would observe in the world around them. A weakness of the lab is that it gives a significant amount of impendence and ill-structured problems without any scaffolds or guided reflection. This lab is hard to complete without prior knowledge about planning an independent investigation. Figure 4.91 shows the simulation that allows for knowledge building about the content in this lab. Figure 4.92 is an example of the simulation slide seen for each part of the lab. Figure 4.93 shows the graphic organizer for this lab.

Figure 4.91. This is a picture of the simulation students observe and build knowledge from about population growth.
Stop One: Submerged Peaks and the Sea that Surrounds Bonaire

The Caribbean Sea that covers the submerged peaks of the Northern Andes is shallow and warm. These beautiful clear waters are home to coral reef ecosystems. These ecosystems are home to a great number of species and are also very fragile. Here, the factors which limit the growth of reef systems are:

- temperature (reef systems can only live in water that is warmer than 18 degrees Celsius, or 64.4 degrees Fahrenheit, and no warmer than 32 degrees Celsius, 89.6 degrees Fahrenheit)
- clear, shallow water (corals can only live in clear water that is approximately 160 feet or less because they need to be exposed to high levels of sunlight)

Figure 4.92. This image is representative of the information students see when they click on each stop in the tour for this simulation/lab.

Coral, Algae, Temperature, and Light

Coral and algae enjoy a unique mutualistic relationship where the algae provide energy from the sun through photosynthesis, while the coral provides protection and a nutrient-rich environment for the algae.

Figure 4.93. Graphic organizer for Lab 2: Helps classify the limiting factors in species diversity.

Lab 3 – 1.05 Variables: Experimenting with tulips. This lab builds on lab 1.04 The Scientific Method by having identification of the variables from the Pisa tower experiment. The
learning objective for this lab is to be able to identify the variables in an experiment and understand the importance of variables in science. The lab posed a research question and gave the hypothesis that needed to be used. The tables in Figures 4.94 and 4.95 show the simulation before and after interaction.

![Simulation Table]

*Figure 4.94. The simulation before interaction.*
Figure 4.95. Simulation after clicking data points to reveal tumor growth.

The explanation for confounding variables shows that this data table has too many variables and it is impossible to test the lab-generated hypothesis that a tulip will grow 4 cm in a day. The lab requires interaction with the simulation to reveal the data points but does not ask for prior understandings with variables, scaffold understanding, or use any prompt or feedback in the lab to ensure that students would be staying engaged with the content. This lab does not control confounding variables or give independence over the experiment.

This lab does not have an assessment although this is not clear as on the experiment page the text concludes with “now you know the basics about variables and how important they are in experiments! Let’s move to the activity page.” However, the activity page does not assess understanding. The lab is limiting in that it does not allow students to come up with their own question to test and does not require anything more than clicking on the mouse to view the tulip growth.
Lab 3.07 - Graphing and predicting earthquakes. The learning objectives for this lab are to learn about what causes and how to measure the intensity of earthquakes. The descriptive sequence for this lab is present in the form of a narrative that asks questions about what the triangle markers mean in the map shown in Figure 4.96.

![Map of seismic activity centers in the United States](image)

*Figure 4.96.* This map introduces the triangles used to locate the seismic activity centers in the United States.

This lab introduces the activity by providing background knowledge on the different types of waves that can occur during an earthquake. The lab does not ask for understanding of these concepts or scaffold individual understanding of the different wave types. The lab introduces how the intensity of earthquakes are measured and graphed by using the Richter scale. The use of patterns to demonstrate how earthquakes behave is shown to students in Figure 4.97. This is descriptive and does not ask for identification of the different types of earthquake shocks.
after seeing this example. The lab, therefore, does not scaffold or prompt the context-interaction to build individual understanding from the lab (Ally, 2004).

Figure 4.97. This figure is introducing how earthquakes look on a map in preparation for their graphing activity.

The main activity for this lab is to graph actual earthquakes that have happened using a chart type selected and hypothesize on the safest place to live based solely on the earthquakes that occur there. To build on a more familiar concept, the types of graphs are introduced using a survey of what students would eat for lunch as seen in Figure 4.98.
The lab does not provide a lot of guidance on which graph would be best to display earthquake data and provides no feedback when students would be making their selection. The directions ask students to make a graph but does not show how to make a graph in any graphing program. The directions ask students to “find the average magnitude of earthquakes for both areas (California and Alaska) based on the data you were given.” However when looking at the pictures only three of the four pictures have a magnitude level listed under them so it is not clear how many or what measurements are supposed to be used. Figure 4.99 shows the ambiguity of the data points.
In Alaska, earthquake damage is a little harder to see. Some remote areas are only accessible by air. Although Alaska may not be densely populated like much of California, Alaska is home to an oil pipeline that carries oil across much of the state. Earthquakes have the potential to damage the pipeline and cause a disastrous oil spill.

© Public Domain

Here you see Denali Fault quake damage
In this same quake, the road shifted eight feet in some places adjacent to the pipeline.

South Richards area, pipeline appears unharmed where the road, not far from it, has shifted a good bit.

© Public Domain

**Figure 4.99.** In this image it is not clear what data points should be used when making the graph.

This lab provides an opportunity to build meaning from context-interaction, however there is limited guidance or feedback when interacting with the lab and constructing their graphs. This limits the context-interaction. This lab is an ill-structured problem in that there are multiple outcomes to present information, but ill-structured problems without guidance or feedback can lead to the failures described in pure discovery-based learning (Mayer, 2004).

**Cyber Charter E Summary**

As can be seen from the chart illustrating which labs held which markers of inquiry, there were entire markers that no labs from this school addressed. The labs did at least partially reach six of the eight science practices and either explicitly or implicitly reached all seven of the crosscutting concepts.
Markers and supports related to communicating what was found or interacting with peers and the instructor were not enabled through the lab and LMS. This is concerning when looking at the importance of communication towards building meaning and an understanding from the lab (Quinn et al., 2012) and repeats the issue Hoadley (2000) identified that rich online discussion and communication is difficult to implement.

Another concerning absence of these labs is the lack of scaffolding, activating prior knowledge, or providing feedback. The labs do not ask for the student perspective, prior experiences, nor do they give feedback from the labs as the scripts are not dependent on student actions. Regardless of if the student understands or does not understand, the script stays the same and limits the ability to ask questions or articulate understanding. Edelson and Reiser (2006) emphasize the importance of scaffolds in having students construct information from data. A striking example of this is when there is an expectation in the fourth lab to construct and interpret a graph of the dangers of earthquakes to determine the optimal place to live without any scaffolds or supports.

The final notable absence from these labs is the combination of ill-structured problems in that there are multiple ways to arrive at a solution in two of these labs without any scaffolds to interact with these ill-structured problems. Jonassen (1997) identifies one component of an ill-structured problem as having not clear outcomes or certainties in the problem. Three of these four labs had some level of ill-structured problems. However, the lack of support in helping to solve these problems could be a problem if the students do not have the ability to select the right type of graph or to control variables in a blended experiment. The computer-simulation portion of all of the labs controlled all of the confounding variables which is consistent with what Chen (2010) found in 80% of the PhET virtual labs that he analyzed using a content analysis.
In addition to the science practices, crosscutting concepts, and constructivist supports there were emerging categories not identified as markers or support before the analysis began. These emerging categories identified from this lab such as being ‘text-lite’ and keeping in one browser window can be related to the flow of the learning experience (Rosin, Ro, Klein, & Guo, 2009). From my experience in completing the labs, any lab that required me to leave the browser window left me without a clear picture of what I was doing and disconnected me from the main concept of the lab.

**Numerical Summary of the Case Studies**

Altheide (1987) and Krippendorff (2012) emphasize that at the conclusion of a content analysis a numerical summary of the information should be presented to present a concise summary of the findings. In this study, all of the components of either science practices, crosscutting concepts, or constructivist supports/learning environments have been tabulated according to their percent of presence in the science labs both by school and by component across schools. Table 4.6 shows the percentage by school for each science practice. The science practice was either fully or partially identified in the lab. For a practice to be fully present it needed to give the control to the student in completing the practice.

**Table 4.6**

<table>
<thead>
<tr>
<th>Science Practice Identified (Fully or Partially) by School</th>
<th>School A</th>
<th>School B</th>
<th>School C</th>
<th>School D</th>
<th>School E</th>
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</thead>
<tbody>
<tr>
<td><strong>Existing (ex) or Emergent (em)</strong></td>
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<td>Partially</td>
<td>Fully</td>
<td>Partially</td>
<td>Fully</td>
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<td><strong>Science Practices</strong></td>
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<td>2</td>
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<tr>
<td>Developing and using models</td>
<td>Ex</td>
<td>3</td>
<td>1</td>
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Planning and carrying out investigations

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Analyzing and interpreting data

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<th>2</th>
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Using mathematics and computational thinking

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Constructing explanation

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Engaging in argument from evidence

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Obtaining, evaluating, and communicating information

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Note. A dash means this marker was not identified in the virtual labs.

Table 4.7 shows the crosscutting concepts identified by school. The crosscutting concepts were labeled either explicitly or implicitly depending on if the lab made the concept visible through the design of the lab. If the concept was clearly visible through a prompt or other identifiable marker it was explicit and if it was a concept that I picked up with having expertise to recognize the concept it was marked as implicit.

Table 4.7

The Crosscutting Concepts Identified by School Implicitly or Explicitly

<table>
<thead>
<tr>
<th></th>
<th>Ex</th>
<th>A</th>
<th>School</th>
<th>School</th>
<th>School</th>
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<td>A</td>
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<td>C</td>
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<td>E</td>
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Identifiable Markers (maximum n=4)

Crosscutting Concept Patterns

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<th>1</th>
<th>2</th>
<th>1</th>
<th>1</th>
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</thead>
</table>
Table 4.8 shows the constructivist design features and supports identified by cyber charter school. For the constructivist feature to be fully present it had to be enduring throughout the lab. This feature had to appear more than twice throughout a lab. If a constructivist design feature was partially present that meant it appeared only once throughout the lab.

Table 4.8

The Constructivist Design Features Identified by School

<table>
<thead>
<tr>
<th>Identifyable Markers (maximum n=4)</th>
<th>Supports from labs to help with markers</th>
<th>Communicati</th>
<th>Descriptive sequences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ex or E</td>
<td>x</td>
<td>E x</td>
</tr>
<tr>
<td>Cause and effect</td>
<td>- 1 1 1 2 2 - 3 - - - - - - - - - - -</td>
<td>2 - - - - - - - - - - - - - - - -</td>
<td>3 1 1 2 1 3 2 2 2 2 2 2</td>
</tr>
<tr>
<td>Scale, proportion, and quantity</td>
<td>- - - - - - 3 - - - - - - - - - - - -</td>
<td>- - - - - - - - - - - - - - - -</td>
<td>- - - - - - - - - - - - - -</td>
</tr>
<tr>
<td>Systems and system models</td>
<td>- - - - - - - - - - - - - - - - - - -</td>
<td>- - - - - - - - - - - - - - - -</td>
<td>- - - - - - - - - - - - - -</td>
</tr>
<tr>
<td>Energy and matter</td>
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<td>- - - - - - - - - - - - - - - -</td>
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<td>Structure and function</td>
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<td>- - - - - - - - - - - - - -</td>
</tr>
<tr>
<td>Stability and change</td>
<td>- - - - - - - - - - - - - - - - - - -</td>
<td>- - - - - - - - - - - - - - - -</td>
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Note. A dash means this marker was not identified in the virtual labs.
<p>| Scaffolds present (fading, channeling, modeling) | E | 4 | - | 1 | - | 1 | 2 | 3 | - | - | - |
| Metacognitive scaffold | E | 2 | - | - | - | 1 | - | 2 | - | - | - |
| Reflection scaffold | E | 3 | - | - | - | - | 1 | 1 | 1 | - | - |
| Sense making scaffold | E | 3 | 1 | 1 | - | 1 | 1 | 3 | - | - | - |
| Distributed learning support (not scaffold) | E | 1 | 2 | - | 2 | - | 4 | 3 | - | - | 1 |
| Control in hands of students – Independence script | E | 1 | 1 | 2 | - | 1 | 1 | 1 | - | 1 | 2 |
| Cognitive tool | E | 3 | 1 | 2 | 1 | 2 | 1 | 3 | - | 1 | 1 |
| Authentic activities | E | 3 | - | 1 | 1 | - | - | 2 | 1 | 1 | - |
| Presenting material from more than one perspective/modality | E | 1 | 1 | 1 | - | 1 | - | 4 | - | - | - |
| Confounding variables controlled by lab | E | 2 | 2 | 3 | - | 1 | 3 | 3 | 1 | 2 | - |
| <strong>Design features in learning environment</strong> | | | | | | | | | | | |
| Well-structured problem | E | 3 | 1 | 2 | - | 1 | 2 | 4 | - | 1 | - |
| Ill-structured problem | E | 2 | 2 | 2 | - | 1 | 2 | - | 1 | 2 | 1 |
| Learner-context interactions scripts | E | 3 | 1 | 1 | - | 1 | 2 | 1 | 1 | - | 2 |
| Learn content to solve a problem | E | 3 | - | 3 | 1 | 1 | - | 2 | - | - | 2 |
| Accept multiple student explanations at beginning of lab | E | 2 | 1 | - | - | 1 | - | - | - | - | - |</p>
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<td>Activating/asking about prior knowledge</td>
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<tr>
<td>Blended virtual simulation and home-physical lab</td>
<td>E</td>
<td>-</td>
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<tr>
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<td>2</td>
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<td>-</td>
</tr>
<tr>
<td>Multiple opportunities to fail</td>
<td>E</td>
<td>3</td>
<td>-</td>
<td>2</td>
<td>-</td>
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<td>1</td>
<td>2</td>
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<tr>
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<td>E</td>
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<td>2</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>1</td>
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</tr>
<tr>
<td>Gives students information on the equipment they are using</td>
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<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Connecting students to the larger scientific community</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
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</tr>
<tr>
<td>Incorporate videos directly into the lab</td>
<td>E</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
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</tr>
</tbody>
</table>
Informal assessment built into the end of the lab

| E | M | 3 | - | - | 2 | - | 3 | - | - | - |

Lab controls extraneous tasks for student

| E | M | 3 | - | 2 | - | 3 | - | 3 | - | 2 |

Involves the parent/guardian in discussing the lab with their student

| E | M | 1 | - | - | - | - | - | - | - | - |

Explicitly reduces time

| E | M | 3 | - | 2 | - | 2 | - | 1 | - | 1 |

Includes standards and learning objectives at the top of the page

| E | M | - | - | - | - | 2 | - | 4 | - | - |

Limited browser functionality

| E | M | - | - | - | - | - | 1 | - | - | - |

**Note.** A dash means this marker was not identified in the virtual labs.

The numerical summary of the markers seen has also been analyzed with respect to total identification across schools. The following three tables represent the summary across all five schools which comprises 20 virtual labs. Whereas, the previous tables were presented according to count by school, these tables are presented according to percentage of whole.

Table 4.9

**Science Practices across All Schools**

<table>
<thead>
<tr>
<th>Science Practices</th>
<th>Existing (ex) or Emergent (em)</th>
<th>Present outside of lab in LMS</th>
<th>Present</th>
<th>Partially Present</th>
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<tbody>
<tr>
<td>Asking Questions</td>
<td>Ex</td>
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<td>5</td>
<td>35</td>
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<tr>
<td>Developing and using models</td>
<td>Ex</td>
<td></td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Planning and carrying out investigations</td>
<td>Ex</td>
<td></td>
<td>35</td>
<td>35</td>
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<tr>
<td>Crosscutting Concepts across All Schools</td>
<td>Existing (Ex) or Emergent (Em)</td>
<td>Explicit</td>
<td>Implicit</td>
<td></td>
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<tr>
<td>----------------------------------------</td>
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<td><strong>Crosscutting Concepts</strong></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Patterns</td>
<td>Ex</td>
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<tr>
<td>Cause and effect</td>
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<td>40</td>
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<tr>
<td>Scale, proportion, and quantity</td>
<td>Ex</td>
<td>15</td>
<td>35</td>
<td></td>
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<tr>
<td>Systems and system models</td>
<td>Ex</td>
<td>5</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Energy and matter</td>
<td>Ex</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Structure and function</td>
<td>Ex</td>
<td>15</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Stability and change</td>
<td>Ex</td>
<td>15</td>
<td>65</td>
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</tbody>
</table>

Table 4.11

Constructivist Design Features Across All Schools

<table>
<thead>
<tr>
<th>Supports from labs to help with markers</th>
<th>Existing (Ex) or Emergent (Em)</th>
<th>Fully</th>
<th>Partial</th>
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<tr>
<td>Communication Features (peer-peer and peer-instructor)</td>
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<tr>
<td>Descriptive sequences</td>
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<tr>
<td>Scaffolds present (fading, channeling, modeling)</td>
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<td>45</td>
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<tr>
<td>Metacognitive scaffold</td>
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<td>25</td>
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<tr>
<td>Reflection scaffold</td>
<td></td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Sense making scaffold</td>
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<td>10</td>
</tr>
<tr>
<td>Distributed learning support (not scaffold)</td>
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<td>50</td>
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<tr>
<td>Control in hands of students – Independence script</td>
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<tr>
<td>Cognitive tool</td>
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<td>25</td>
<td>25</td>
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<tr>
<td>Authentic activities</td>
<td></td>
<td>35</td>
<td>10</td>
</tr>
<tr>
<td>Presenting material from more than one perspective/modality</td>
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<tr>
<td>Confounding variables controlled by lab</td>
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<td>Design features in learning environment</td>
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<td>Ill-structured problem</td>
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<td>Learner-context interactions scripts</td>
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<tr>
<td>Learn content to solve a problem</td>
<td></td>
<td>45</td>
<td>15</td>
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<tr>
<td>Accept multiple student explanations at beginning of lab</td>
<td></td>
<td>15</td>
<td>5</td>
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<tr>
<td>Virtual experiment (prepping equipment)</td>
<td></td>
<td>25</td>
<td>15</td>
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<tr>
<td>Simulation (no prepping of equipment)</td>
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<td>Manipulate materials (experiment)</td>
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<td>Observe actions (simulation)</td>
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<td>Reflection on experimental design for students</td>
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<td>Acknowledge complexity of empirical work for students</td>
<td>Ex</td>
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<tr>
<td>Activating/asking about prior knowledge</td>
<td>Em</td>
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<td>Everything housed in one screen/window</td>
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<td>“Text-Lite”</td>
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<td>Blended virtual simulation and home-physical lab</td>
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<tr>
<td>Engaging Introduction</td>
<td>Em</td>
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<td>5</td>
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<tr>
<td>Multiple opportunities to fail</td>
<td>Em</td>
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<td>Dual navigation within the lab</td>
<td>Em</td>
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<tr>
<td>Gives students information on the equipment they are using</td>
<td>Em</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Connecting students to the larger scientific community</td>
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<td>5</td>
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<tr>
<td>Incorporate videos directly into the lab</td>
<td>Em</td>
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<tr>
<td>Informal assessment built into the end of the lab</td>
<td>Em</td>
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<tr>
<td>Lab controls extraneous tasks for student</td>
<td>Em</td>
<td>65</td>
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<tr>
<td>Involves the parent/guardian in discussing the lab with their student</td>
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<tr>
<td>Explicitly reduces time</td>
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<tr>
<td>Includes standards and learning objectives at the top of the page</td>
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<tr>
<td>Limited browser functionality</td>
<td>Em</td>
<td>5</td>
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</table>

*Note.* Dash means this feature was not identified in the labs.

The data from Tables 4.6-4.11 is summarized graphically to visually see the markers from the lab. The first graph shows the science practices that are identified in the lab.
Figure 4.1a. This graph shows the science practices in all of the labs. The blue bar is science practices present in the lab and the orange bar is the science practices partially present.

The second graph shows the crosscutting concepts that are fully present (explicit) or partially present (implicit) in the labs. All of the crosscutting concepts were at least partially present in greater than 50% of the labs.

Figure 4.2a. The crosscutting concepts seen in the labs. The labs reached all of the crosscutting concepts, at least implicitly, at a rate greater than 50% of the labs.
The constructivist features of the lab are separated into two different graphs to make them easier to interpret. Not every component of the lab is beneficial to student learning in all contexts. For example, Chen and Klahr (1999) found that the labs do not have to control for confounding variables if the students are instructed on how to avoid using confounding variables. This is simply describing their presence in the lab.

![Constructivist Features of Lab](image)

Figure 4.3a. First graph of constructivist features of the lab.

The second graph shows the remaining of the constructivist design features that were identified by the literature prior to investigating these virtual labs. There were largely absent features across the virtual labs. For example, only 5% of the labs had students reflect on experimental design. This is similar to Chen’s (2010) finding that less than 1% of labs had students focus on errors in experimental design or the complexity of empirical work (Crippen et al., 2013). An important connection was that in ill-structured labs the use of scaffolds and good descriptive sequences were essential to help structure students problem solving. Ill-structured problems without support run the risk of a discovery-based learning environment (Mayer, 2004).
A notably absent feature from the majority of labs was asking students their opinion (12%) or prior knowledge (30%) while they were completing the labs.

Another interesting finding was that some features that were implied as mutually exclusive in the literature such as experiment or simulation (Crippen et al., 2013). Students can prep experiments in some parts of the lab, run simulations in others, manipulate materials and observe all in the same lab.

Figure 4.4a. Second graph of constructivist design features in the cyber charter school virtual labs

The final graph shows the emerging categories that were not identified before this study began as directly related to virtual labs. Some of these trends are related directly to cyber charter schools such as asking the student to get the parent involvement. Other features such as being able to navigate throughout the lab, having multiple opportunities to fail, and reducing the text students have to read to understand reduces the cognitive load on students and allows them to review and go back to the lab if they have a question. Features like multiple opportunities to fail and being able to review the lab promote a mastery-based education in line with what the
teachers emphasized in the interviews and seen in the theme on allowing students to resubmit revisions of the labs.

Figure 4.5a. Features of the virtual labs that were not explicitly identified from the literature.
Chapter 5

Discussion

The final step in ECA is to report on the findings while placing them in the context of relevant literature (Altheide & Schneider, 2013). In Chapter Four teacher interviews were used to describe how labs are used in cyber charter schools, ECA was used to demonstrate the potential engagement with science practices and crosscutting concepts these labs offer students. Constructivist supports through descriptive texts, graphical illustrations, and a numerical summary. In this chapter, the results are situated in the framework of existing literature, emergent findings discussed, implications described for science laboratory design in cyber charter schools, and consider the limitations of this study and ideas for future research.

According to Zhang & Wildemuth (2009) the goal of qualitative content analysis is to pay “attention to unique themes that illustrate the range of the meanings of the phenomenon” (p. 2). The specific goals of this study were to identify the range of practices related to science labs in cyber charter schools, to determine the potential of those labs to engage students in science practices and crosscutting concepts, and to describe the extent of constructivist supports that aid students learning from the labs. Describing and analyzing the labs as they currently exist and are being used in cyber charter schools contributes to our understanding of the design and use of virtual labs in the cyber charter-school context. This research thus gives ‘thick descriptions’ (Geertz, 1973) of the labs that cyber charter schools use in order to identify the presence or absence of science practices, crosscutting concepts, and constructivist design supports in those labs.
The Range of Virtual Labs

Students in different cyber charter schools use different software, curricula, and LMSs. These decisions impact the types of labs students complete. In this study, 10% of the labs promoted communication as a science practice and there were communication features in 10% of the labs as a constructivist design. The labs with communication opportunities present for students were exclusively used from Cyber Charter School A. Students reflected on experimental design in 5% of the labs, and 5% of the labs acknowledged the complexity of empirical work for students. This confirms the findings in Crippen et al., (2012) that labs engage in discourse only 6% of the time, that 2% of labs foster collaboration, and that 1% of labs promote reflection on experimental error, and that the labs did not discuss the complexity of empirical work.

In considering the range of phenomena (Zhang & Wildemuth, 2009), Crippen et al. (2012) have found that online teachers use a variety of lab types, including ‘hands-on’ labs, simulated labs, and virtual labs. This current study had one lab that was blended between online and physical experimentation. Students had to prep the equipment in 35% of the labs and run a simulation in 60% of the labs. This current study’s results challenge earlier assertions by Moore & Kearsley (2011) that online schools typically do not rely on teachers to design curricula, as three of the schools gave teachers some level of autonomy in designing the instruction. Administrative decisions about curricula impacted the labs used. For example, Teacher 3 from Cyber Charter School C expressed that she only used open-lab products because the school may purchase a subscription to closed-access labs and then not renew it, meaning that all of the work is lost when creating lessons with those labs.

Parental/guardian/learning-coach engagement is mentioned on all of the cyber charter school Web site. The teachers demonstrated an interest in having parents/guardians help students
with their labs, but they were largely unsuccessful in encouraging this. This can be seen in the findings from Cyber Charter School D.

**Cyber Charter School D:** I really haven’t found a good way. Either a parent is going to be involved or not going to be…but they are not involved period.

Huerta et al., (2006) have emphasized the important role of the parent in K-12 online education, but they do not give specific recommendations on how parents should be involved. It is evident from conversations with teachers that while all teachers want and value parent/guardian involvement, it is lackluster. An important consideration that is relevant for cyber charter school students is parental expectation of involvement with the labs. Huerta et al., (2006) note that parental guidance and participation is expected when managing cyber charter-school students. This expectation stems from how schooling is defined in cyber charter schools (Ahn, 2011).

Equitable access to resources and support is a concern for online students (Sherry, 2003). In this study, it was found that teachers made themselves available to students in and out of class. This is an advantage for students as Cavanaugh, Gillian, Kromrey, Hess, & Blomeyer (2004) emphasize the role of the teacher for online students. However, access to resources or types of centers was not consistent among students. More specifically, it was found that school resources were not consistent with the notion of geographic flexibility. For example, Cyber Charter School A had physical drop-in centers in limited geographic regions while Cyber Charter School B had drop-in centers for students in the same area as the school but not for students in different parts of the state. This variation in learning environments can alter the implementation of labs for students. The policies and their implementation may differ among cyber charter schools and impact the curricula and supports for cyber charter-school students. The policies help to define
what schools is in those schools (Ahn, 2011). While geographic flexibility is established and not a barrier for cyber charter-school students (Ahn, 2011), equitable access to resources based on geography is not.

A common challenge expressed among teachers was the difficulty of inter-peer communications. At none of the cyber charter schools did the school have the students communicate with one another through any remote videoconferencing software such as Zoom or Skype. Considering the importance of communication and discussion when doing science labs or learning in a constructivist environment (Ally, 2004; Hoadley, 2000; Quinn et al., 2012; Rummel & Spada, 2012) it is concerning that the design of the virtual labs for students who are already in an isolating environment does not allow them to easily communicate with their peers about the labs. This design could make the experience of doing science in a cyber charter school quite different than the experience in a brick-and-mortar school where students could have conversation with their peers while they are doing their labs.

However, there were variations in the communication between students because some of the schools used class time to support students in their labs (Cyber Charter School B) where other schools did not have live class time to do this (Cyber Charter Schools C and D). Asynchronous discussion is considered a key component of distance education in higher education (Gregg, 2016, Schrire, 2006) but this was an unsuccessful form of communication for schools with labs. Even synchronous communication about the science labs was challenging for many of the teachers as students went off-task in the chat room.

**Cyber Charter School C, Teacher 2:** It depends, sometimes it happens and sometimes it doesn’t. Like I said that would be an ideal situation but sometimes it is more difficulty to get to every single one of them on every single lab.
Other schools had more success with using live lessons to discuss the results of the lab. 

**Cyber Charter School A:** When we do live lesson…they will interact and we will talk you know what happened, how did your thermometer work?

The findings in this study regarding those responsible for designing curricula may contradict earlier findings from Moore and Kearsley (2011) that suggest teachers are not in charge of designing the curricula in online schools. At Cyber Charter School B the middle school science teacher was given autonomy over how and when she did virtual labs with the students. At Cyber Charter School C the teachers were able to use a variety of software, webcam displays, and observations. At Cyber Charter School D the teacher had access to many different tools such as Dreamweaver, TACKK, PDF reader tools, and open virtual labs, all of which enabled the creation of a comprehensive learning environment for the students. At Cyber Charter Schools A and E, the curricula was from purchased providers. While a certain division of labor in designing and instructing courses is common at dual-mode institutions (Sumner, 2000) this study shows that the decisions driving division of labor warrant further investigation at the K-12 level.

A potentially significant finding from the teacher interviews was that the environment of cyber charter schools serves as fertile ground for mastery-based learning models. The theme of teacher as willing to give students feedback and accept revisions until the students demonstrate mastery is a poignant example of this.

**Cyber Charter School E:** I go over it (the lab report) and give them lots of input…I don’t even make a penalty in terms of doing it a second time.

**Cyber Charter School D:** Definitely with this population I give them the chance to go back through and make corrections now whether they do that…
**Cyber Charter School A:** By communicating, by allowing them to redo assessments when they make mistakes.

In considering the virtual frog dissections lab the teacher (Cyber Charter School B) discussed how the students “like to go back and cut something different to see what the body looks like without that organ.” The labs promote this mastery-based learning because they frequently allow students to fail and try again (40%) or manipulate variables until they are able to grasp what the cause-and-effect in the lab that stems from manipulating variables (ex: the natural and artificial selection lab, the bunny PhET lab) In a virtual lab there is more opportunity to fail because there is no chance of irreversibly damaging the experiment or ruining your results (de Jong et al., 2013). Mastery-based learning originated from work by Block and Burns (1976) that suggests “all students can learn well…most of what is taught” (p. 4). However, this does not happen in segmented steps but rather on a gradient for each student. Mastery of a subject or competency is a complex process involving:

- The quality of instruction
- The ability of the student to understand that instruction, and
- The student’s aptitude for that subject (Blocks & Burn, 1976, p. 5).

By being willing to accept multiple revisions and help individual students with their learning, the teachers interviewed for this study promote a mastery-based approach to learning in their classrooms.

As a result of the interviews with teachers a need for a clear definition of a “virtual lab” in the cyber charter-school contexts emerged. Teachers frequently commented…”I don’t know if you would consider this a lab” or “This is a portfolio but not really a lab in my eyes.” A clear definition of a virtual lab could help guide teachers to select materials that meet these criteria.
Ultimately, teachers considered using the scientific method, questions involving the nature of science, and interactivity to be components of “virtual lab” experiences. This is different than the definition of lab according to the *NRC Framework*. According to Quinn et al., (2012) the *NRC Framework* identifies laboratory experiences as serving as a means for students to learn content through science practices. In a science lab, students work collaboratively to understand a phenomenon (Hofstein & Lunetta, 2004). The accepted definition of science labs from the *NRC Framework* is: “laboratory experiences provide opportunities for students to interact directly with the material world (or with data drawn from the material world), using the tools, data collection techniques, models, and theories of science.” (Singer, Hilton, & Schweingruber, 2005, p. 3).

**Cyber Charter School D:** So for me a lab is anything that applies the scientific method so going through maybe just any one of the inferring, classifying, making observations, anything that deals with the nature of science is for me a lab.

There were other lab aspects that influenced teachers’ decisions but were not reflected in the *NRC Framework* definition. For instance, the level of interaction between the lab and the student does not appear in this definition, but it was commented on by teachers who decide which labs to use.

**Cyber Charter School C, Teacher 2:** If it is an interactive experience for the student that in my mind constitutes a lab even though you don’t have a beaker in front of you.

The teachers’ interviews suggested a multifaceted approach to defining science labs for students beyond what is seen in this definition for science labs regardless of learning environment.
Science Practices and Crosscutting Concepts

Virtual labs have the potential to adequately engage students in investigating (70%), collecting and analyzing data (60%). The wondering in science is missed in these labs because there is very little acknowledgement of prior knowledge (25%) or asking research questions (partially present in 35% labs, fully present in 5%) and forming hypotheses. It is the goal of the NRC Framework and NGSS to make students scientifically literate. Laboratory experiences can help achieve this goal by promoting students’ engagement with science practices and crosscutting concepts (Quinn et al., 2012). Constructivism can also help to facilitate these experiences by helping students to actively construct and build on their prior knowledge (Seimars et al., 2012). However, asking about prior knowledge (25%) or accepting multiple student explanations (20%) was not commonly seen.

The NGSS further confirms the importance of using inquiry methods when it states that “students should develop an understanding of science as a whole – the wondering, investigating, questioning, data collecting, and analyzing” (NGSS: Appendix H, 2013). This study shows that while the majority of virtual labs engage students in some sort of investigation and data analysis, they do not always do so. In addition, labs do not typically ask students about their prior knowledge or expect them to form research questions. Of course, it is hard to have students create their own research questions in predesigned labs that are limited in their personalization but it is still possible. The earthquake lab from Cyber Charter School E accomplishes this by having students ask questions about the best places place to live based on the earthquakes in that area. In doing so, the students are implicitly learning to ask research questions and developing hypotheses based on their thinking as well as revising those hypotheses based on the results of their investigation.
In this study, 15% of the labs had all eight science practices in one lab, 20% had five, 10% had four, 35% had three, 5% had two, and 15% had one science practice present in the lab. Integrated science practices to model to students that science is “a theory-building steeped in practices and epistemological norms” (Duncan & Rivet, 2013, p. 397). For example, asking students to interpret data but then not engaging in argument from evidence or communicating their findings can reduce the practice of science from being connected within the broader theory to a lab resembling the scientific method (Duncan & Rivet, 2013).

This study demonstrated that as a whole the science labs in cyber charter schools cover at least some of the science practices and crosscutting concepts that help students develop science literacy. However, the consistent weakness of having students ask questions (fully present in only 5% of labs), engaging in argument from evidence (fully present in only 10% of labs), and communicating findings to the peers and teachers (fully present in only 10% of labs is concerning. From a systemic perspective, that labs engage students with some science practices, but not all, does not develop students’ holistic understandings of science practices and the scientific process (Quinn et al., 2012).

This holistic experience requires that students learn content knowledge such as the core ideas of the NGSS, while simultaneously engaging with science practices and crosscutting concepts (Quinn et al., 2012). The labs from Cyber Charter Schools A (three labs), B (four labs), C (one lab), D (two labs), and E (two labs) met this goal helping students to learn content while solving problems, and thus promoted content-learning while engage students with science practices and crosscutting concepts. Chen (2010) in his content analysis of PhET virtual labs, stresses the importance of evaluating virtual labs on the basis of more than the labs’ ability to teach conceptual knowledge. This study accomplished that goal by analyzing labs for science
practices and crosscutting concepts. Pyatt and Sims (2011) acknowledge this as a limitation of their study on virtual labs because they looked only at the content students learned. Jonassen (1999) notes that this constitutes learning content through solving problems rather than an application of content in problem-solving. Learning content knowledge, such as the core ideas of the NGSS without considering science practices and crosscutting concepts, limits the potential of virtual labs (Quinn et al., 2012).

There is a difference between well-structured and ill-structure problem-solving. Among the labs in this study, 50% had some level of ill-structured problem-solving while 70% had well-structured problem-solving for students. An example of an ill-structured problem-solving lab is the natural and artificial selection lab from Cyber Charter School A. This lab includes ill-structured problems with unclear outcomes and puts control in the hands of the students who are working with the simulation. An example of a well-structure problem-solving lab is the virtual frog dissection lab. This lad does not give students control or the ability to actually ‘manipulate’ the virtual equipment. The authentic nature of ill-structured problem-solving is important for students to experience the types of problem-solving encountered by experts (Chin & Chia, 2006) and engage with tasks with multiple solutions (Jonassen, 1997). The results of this study confirm that while there are labs that do not have aspects of ill-structured problem-solving, it is not an either-or issue, some labs have both ill-structured and well-structured problem-solving. For example, the mouse genetics (one trait) lab from Cyber Charter School A includes both well-structured and ill-structured problem-solving. This contradicts findings that suggest the vast majority of problems encountered in schools are designed to be well-structured even though most of the problems encountered in work scenarios are ill-structured (Shin, Jonassen, & McGee,
2001) and moreover, that the majority of virtual lab software use rely on cookie-cutter models that limit the amount of uncertainty to which the students are exposed (Chen, 2010).

Crosscutting concepts have not been investigated in previous studies. Many of the labs in this study had crosscutting concepts present, although they were often implicit (34%) rather than explicit (19%). There was not an equal distribution of crosscutting concepts among the labs. Systems and system models were only addressed in three of the labs while energy and matter were only addressed in four of the labs. In contrast, patterns appeared in twelve of the labs and cause-and-effect was seen in thirteen of the labs. This suggests that labs need to be designed in a way to make crosscutting concepts more explicit for students through directed attention to these concepts and intentional student learning about these concepts. Novice learners do not tend to think about topics in multiple ways or go beyond surface-level understandings (Cook, 2006). It is beyond the scope of this study to determine what students are learning from the crosscutting concepts or if they learn at different levels depending on whether the crosscutting concepts are implicit or explicit. However, with scaffolds such as channeling, modeling, and fading (Pea, 2004) students can be supported in learning crosscutting concepts. Explicit crosscutting concepts (Quinn et al., 2012) were not seen as frequently as implicit crosscutting concepts. Krajcik and Blumenfeld (2006) stress the importance of making patterns or knowledge about the organization of a field explicit to students.

**Constructivist Learning Environment**

Constructivist features that foster deep learning such as ill-structured problems (50%), scaffolds (55%), cognitive tools to promote thinking (50%), and informal assessments/feedback (40%) were seen in about half of the virtual labs analyzed. This result validates Sawyer’s (2006) finding that the software used in schools does not support deep learning. The labs provided an
authentic environment 45% of the time and had reflective/metacognitive prompts to help regulate student learning approximately 25% of the time. Computers have the potential to provide an authentic and motivational learning environment for students (Zumbach et al., 2012) but simply placing technology in the hands of a student is not enough to produce the intended learning outcomes. The lack of authentic learning environments and scaffolds in more than half of the labs is concerning. Communication supports for students were seen in 10% of the labs and the ability to connect students to a larger scientific community was seen in 5% of the labs. Rice (2006) notes that students who are supported in their online learning environment produce higher quality work and have greater participation in courses, and students who are able to work with peers on problems are more likely to persist in trying to solve problems (Rice, 2006).

**Scaffolding features.** Only 25% of the labs included a metacognitive component that prompted students to think about their own learning and the process by which they were completing the labs. Metacognitive components help students to self-regulate their learning. Failure to self-regulate is a primary reason why students fail in the online learning environment (Azevedo & Hadwin, 2005). Metacognitive scaffolds can help students to improve their metacognitive skills (Bannert, 2006) by providing support that may be individualized (Azevedo & Hadwin, 2005). Metacognitive prompts can provide a model for students to think of science as an intersection among science practices, crosscutting concepts, and core ideas (NGSS, 2013; Peter & Kistantas, 2010). This study highlights the need to retool the design of virtual labs to give students the opportunity to engage with metacognitive prompts.

Among the labs in this study, 25% included a reflective scaffold. In addition only 5% of the labs included a partial reflection the experimental design of the lab. The word “partial” is used to suggest that the reflection focused solely on considerations of sample size rather than
multiple parts of the experimental design (Mendel genetics lab, Cyber Charter School B). All of the reflective scaffolds were found in labs used by Cyber Charter Schools A and D. Reflective prompts can help students to transfer what they have learned to new tasks (Bransford et al., 1999) and articulate what they are thinking while processing information (Sawyer, 2006). The overall lack of reflective prompts is very concerning because students may have difficulty engaging in reflection about material with which they are unfamiliar without scaffolds (Bransford et al., 1999; Davis, 2003).

An interesting relationship between scaffolds, control, independence, confounding variables, and ill-structured problem-solving emerged the labs were completed and analyzed. Ill-structured problems provide students with control and independence during the lab. For example, in the blood-typing lab (Cyber Charter School B), students consider multiple possible outcomes for the type of blood the accident victims are given. The ill-structured nature of the problem means that the students have to analyze how a particular type of blood react to a different type of blood and decide on the right transfusion, this gives students control and independence in how they interact with the lab. More control leads to a greater amount of independence for the student in the lab. However, the terms are not synonymous. For example, a lab could allow students to control all parts of the window but still limits their independence by having scripts that focus attention on parts of the lab. Labs that have ill-structured problems provide students with control through independence because they give the learners the opportunity to make choices in (a) how the lab is set-up; or (b) what variables to use in the lab (Vrasidas, 2000). The labs that give students independence (50% full, 25% partial) are consistent with constructivist learning environments because a constructivist learning environment needs to have “more construction kits and phenomenaria and place more control of the environment in the hands of the learners”
The results of this study thus contradict previous findings from Chen (2010) that suggest only 20% of labs analyzed give students the choice of setting-up the lab. My understanding of independence from the literature also includes variable control and could account for some of the divergent findings of Chen’s (2010) and the current study. The number of labs found in this study that allowed students to prep the equipment (35%) is more consistent with Chen’s (2010) findings.

When analyzing the labs for confounding variables, this study found that labs control confounding variables 50% of the time fully and 15% of the time partially. Controlling confounding variables reduces the uncertainties in a lab and consequentially reduces the amount of ill-structured problem-solving that the lab promotes (Jonassen, 1997). An example of a lab that does not control confounding variables for students is Cyber Charter School B’s skate park energy transfer lab. Students are able to select multiple variables such as skater mass or the height/direction of the skate ramp, during the lab. It is important in a constructivist learning environment that if students are given control of multiple variables they are scaffolded in how to manage those variables. Chen and Klahr (1999) have found that students are able to control confounding variables if they are scaffolded to selectively manage the variables in the lab.

Independence does not exist solely with giving students confounding variables. For example, the mouse genetics (one trait) lab from Cyber Charter School A features independence because the students are able to decide on the number of trials to run when breeding the mice. Although they do not have to her variables to control, the students are given partial independence over this aspect of the lab. Giving students more control in the lab connotes that the problem is likely to be more ill-structured. Ill-structured problems give students more than one solution, more than one way to find the solution, or the choice of what they need to do to find the best
solution (Jonassen, 1997). The mouse lab is a partially ill-structured lab because students are able to choose which mice to save for future breeding, but the worksheet guide limits the amount of uncertainty in the lab.

Fewer than 50% of the labs have metacognitive or reflective scaffolds, while 50% have sense-making scaffolds. When looking at the matrix of all lab components, six of the labs emerge as ill-structured and four are partially ill-structured. Only two of the labs that are ill-structured have metacognitive prompts, four have reflective prompts, and four have sense-making prompts. If a lab has ill-structured problems, it should also have scaffolds and supports for students to engage with these ill-structured problems. It is important for there to be sense-making prompts throughout the lab, but especially at the end so students can reflect on the results of the experiment and their assumptions underlying their interpretation of the results (Karelina & Etkina, 2007). This study did not identify scaffolds temporally, but rather their presence in their labs. Therefore, a limitation of the study is that the specific place where the scaffold appeared was not identified from the analysis. Labs with ill-structured problems need to have scaffolds, descriptive sequences, and cognitive (Chin & Chia, 2005). Without these, labs run the risk of being pure-discovery based learning environment and fulfilling the criticism of constructivist learning environments that Kirschner et al. (2006) lodges: that is, they are too open-ended and without support. Scaffolds help students to complete tasks that encourage them to think more like experts (Bransford et al., 2006) and effectively reflect (Davis, 2003) and metacognate (Azevedo & Hadwin, 2005). Scaffolds were absent from many of the labs analyzed: the labs did not provide fading or contingent support for the students (Sharples et al., 2014). Most of the scaffolds identified were labeled scaffolds because they modeled and channeled for students (Pea, 2004).
**Simulated versus virtual labs.** In this study, 35% of the labs had students prep equipment while 60% of students had students run simulations. In addition, 65% of the labs had students manipulate materials and 65% of the labs had students observe actions without manipulating materials. The labs that had students prep equipment and the labs that had students run simulations were mutually exclusive. However, the divisions between prepping equipment, watching simulations, manipulating materials, and observing actions without manipulations were not perfectly clear. There were three simulated labs that also had students manipulate materials. In addition, five of the labs that had students’ set-up equipment also had them observe the labs at certain points. Nine of the labs that had students manipulate materials at certain points also had students observe actions during other parts of the labs. This confirms Crippen et al.’s (2013) finding of the difference between a simulated and virtual experiment. Simulated experiments do not expect students to prep equipment, while virtual experiments do expect students to do this. However, this disputes Scalise et al.’s (2011) assertion that simulations ask students to be passive observers of the lab while experiments have students actively manipulate labs (Scalise et al., 2011). Some of the labs that had students prep equipment at the beginning had them be passive observers later, while the opposite condition was found in other labs.

**Multiple presentation of information.** Among the labs studied, 20% asked for or accepted multiple student perspectives at the beginning, and 40% of the labs presented information from more than one modality. Constructivist learning environments should allow for multiple perspectives, as each learner constructs their own interpretation of the experience based on many variables such as prior learning and the interaction he or she has had had with the material (Black & McClintock, 1995; Vrasidas, 2000). Asking for the student’s perspective and presenting information from more than one perspective or modality is important in encouraging
deep learning and an understanding of the phenomenon under investigation (Black & McClintock, 1996; Honebein, 1996; Jonassen, 1999). The design of the labs largely neglects these two aspects of the constructivist learning environment.

**Authentic learning.** Authentic activities similar to those conducted by experts in the field were included in 35% of the labs, while 10% of the labs had partially authentic activities. As an example, the gummy bear osmosis lab from Cyber Charter School D has partially authentic activities because the students have to measure the gummy bears but do not actually take the measurements, and the lab asks students to graph the results but the students do not have to actually create the graph. Instead, the teacher takes the measurements for the students and physically inserts the pictures into the lab, while the software automatically creates a graph for the students. A lab with an authentic activity throughout is the blood-typing activity from Cyber Charter School B. This lab depends on the students to solve the problem of finding the right type of blood, making students go through the same process as a medical professional who needs to determine the right type of blood for a blood transfusion. A constructivist learning environment should be authentic in that learners are prompted to engage in cognitive tasks that are also encountered by experts in that field (Honebein, 1996; Jonassen, 1999, Zumbach et al., 2006).

Experts in the medical field are expected to be able to decide which blood to use for a blood transfusion. However, these labs raise the question of whether using software to generate a graph makes a lab inauthentic.

Experts in scientific fields rely heavily on equipment and tools to make their work more efficient. Software is one of those tools, and it is debatable whether students using software to generate the graph makes the activity more or less authentic. Using software does reduce the explicit exposure students have to the crosscutting concepts of cause-and-effect and scale,
Engaging students in investigations of cause-and-effect allows students to better understand how relationships emerge, while discussions of scale and proportion help student to understand the concept of measurement (Quinn et al., 2012). The design of a lab requires tradeoffs in the features that impact the learning environment for students. Regardless as Wilson (1996) states, “Meaningful, authentic activities that help the learner to construct understandings and develop skills relevant to solving problems” are seen in constructivist learning environments.

**Feedback and communication.** Giving feedback to students while they are manipulating the lab through learner actions (Ally, 200) is absent from many of the labs. This feedback is categorized as learner-context interaction within the labs and was present in 55% of the labs. A constructivist learning environment needs to provide feedback to the students (Gott et al., 1996; Jonassen, 1999). The virtual labs that students are using in cyber charter schools may respond to the learner’s actions by, for example, showing the results of DNA gel electrophoresis and giving the students feedback on how they have analyzed this electrophoresis. It is essential that learners are given clear feedback so that they can see how their actions affect the environment (Jonassen, 1999; van den Boom et al., 2004).

Communication is notably absent in several of the virtual labs. Only 10% of the labs engaged in communication about the lab or provided learning environments that promoted communication. In addition, only 5% of the labs attempted to connect students to the larger scientific community. Communication is an important skill for students to develop, as it helps them to articulate what they are thinking, to understand that scientists collaborate when they are working, and to connect to their peers and instructor (Hoadley, 2000; Quinn et al., 2012; Rummel & Spada, 2012). The lack of rich communication features in the labs is concerning.
**Issues in inquiry.** Among the labs considered in this study, 50% included some aspect of a cognitive tool such as helping students to externalize their thinking, asking students about their prior knowledge to help organize what they are learning, or having students apply their own knowledge to solve problems in the lab. A fully present lab was a lab that had two aspects of a cognitive tool, while a partially present lab had to have one component. Cognitive tools as mindtools can help students to tackle some of the commonly encountered issues with inquiry, as identified by Edelson et al. (1999). These issues are: (a) motivation for learners; (b) knowledge of the scientific techniques to use; (c) inadequate content knowledge to use with science practices; (d) inability to self-regulate tasks and behaviors; and (e) lack of a proper learning environment to conduct inquiry tasks. The computer cannot be a mindtool for students if it does not help students to organize, reflect upon, and articulate their knowledge (Jonassen et al., 1998). Mindtools also help students by providing information about the students’ learning processes (Van Joolingen et al., 2007).

**Benefits of Virtual Labs**

Many of the findings that emerged from this analysis suggest the benefits of virtual labs for cyber charter-school students. These findings include making navigation easier (65%), reducing the amount of text students (55%), and allowing for dual or multi navigation within the lab (60%). Virtual labs provide unique advantages over physical labs in that virtual labs require less time for experiments to be completed (45%), enable previously unobservable phenomena to be virtually represented for students (40%), and allow certain items associated with physical labs to be discarded in favor of focusing students’ attention on the important scientific concepts and practices conveyed by the lab (70%) (de Jong et al., 2013). Selectively focusing students’ attention can help to increase the flow for students in their learning (Rossin et al., 2009).
Reduction in time was impossible to determine unless the lab intentionally fast forwarded through a reaction such as in the egg osmosis lab from Cyber Charter School D. There were other emerging categories that came out of this lab and that had not been seen in previous research on cyber charter schools, including encouraging students to discuss findings with their parents/guardians (5%), incorporating videos into the labs (20%), and providing information on the equipment students are using (25%). Anecdotally, online students seem to appreciate when they do not have to manage multiple pages/Web sites for one course. The labs give students multiple opportunities to fail (60%), which is similar to the design of video games that Dickey (2005) and Gee (2003). Connecting students to the larger scientific community helps the students to see the authenticity and connections of what they are learning outside of formal education (Bouillion & Gomez, 2001). Huerta et al. (2006) emphasize the expectation of parental involvement in cyber charter schools. However, the teachers have difficulty with engaging parents, and if the labs prompt students to discuss their findings with their parents this could potentially increase parental involvement in the students’ education.

There are unique challenges of doing science labs in cyber charter schools due to the learning environment of cyber charter schools. The first of these challenges is that the students typically do not communicate with one another when they are completing the lab. They also do not communicate with their instructor if they complete the lab outside of class time. Ally (2004) covered the different types of interaction that could occur in the online environment, the highest of which being learner-context. The other types of learner-learner, learner-instructor, or learner-expert were not seen in cyber charter schools. In addition, for a lab to have learner-context interaction it needed to not limit the conclusions that can be made. None of the labs studied here limited the conclusions that can be made.
Another challenge is that students cannot get immediate and personalized feedback when they would be doing the lab and making sense of what they are learning from the lab. While there were labs such as the gummy bear diffusion lab from Cyber Charter School D that did a better job of providing immediate feedback to the students when they answered a reflective question correctly or incorrectly, none of the labs had personalized feedback based on an individual student response. Considering that the students complete the labs in relative isolation, the design of the lab should take this into account and design feedback prompts/mechanisms to scaffold how students make sense of the lab.

**Future Research**

This study was small, analyzing four virtual labs from five cyber charter schools in Pennsylvania. In addition it was exploratory and did not collect student work from these labs. According to Altheide and Schneider (2013), ECA “is more comfortable with clear descriptions and definitions compatible with the materials, which can help generate concepts appropriate for theoretical testing” (p. 27). In this study I was able to give descriptions of and discuss concepts from the virtual labs. However, a theory was not tested in this study. The use of ECA does not have a hermeneutic focus (Schreier, 2012) and so while this study contributes valuable knowledge about the science practices, crosscutting concepts, and constructivist features of the virtual labs that cyber charter schools use the findings naturally focus on these components and not others.

Ideas for future research are discussed in this section. In this study, there is not a clear demarcation between the science practices, crosscutting concepts, and constructivist design features present in the labs. Frequently the line was fuzzy and I used my judgment to analyze, describe, and categorize these features; while being explicit, reflective, and consistent in these
decisions to preserve the credibility of qualitative interpretivist research (Marshall & Rossman, 2016). From this study, it is known that certain features are more prevalent than others; moreover, while some of the findings confirm what Chen (2010) has found in his content analysis of virtual physics labs the labs described in this study were not always ‘cookie-cutter’. A good first step for future research is thus to repeat this study with a different sample of cyber charter schools in Pennsylvania. This would provide a more comprehensive data set of the content of virtual labs used by cyber charter schools. If this dataset affirmed the emergent findings from this study it could further refine the gradient of presence of the features analyzed. For example, are there areas of control that give students more independence? Are there other areas where giving students’ independence distracts them from the intended learning objectives of the lab? Future results could consider further refine the categories in this study of partially or fully present in the lab and granularize certain activities. For example, limiting the scope to just science practices for one level of analysis could flesh out the levels of ‘presentness’ that these activities have in the virtual labs. A possible tool for further refining would be “the Matrix for Assessing and Planning Scientific Inquiry” that “allows teachers to unpack the cognitive processes and scientific reasoning tasks...along a continuum organized around four levels of complexity and four cognitive processes” (Grady, 2010, p. 33). This matrix could be used as a model for analyzing the science practices, crosscutting concepts, or constructivist supports identified in this study.

After additional research in virtual labs used in other Pennsylvania cyber charter schools has been completed, a content analysis of the labs used in other states could be used to see if what type of lab they use, if the communication practices are different/similar, and if they use physical kits in addition or as a substitution of the virtual labs. This is a worthwhile endeavor, as
it will help to indicate whether the use of virtual labs is widespread and if so, whether students use a variety of virtual labs from different external/internal software programs. It is also worthwhile to determine which schools are sending home physical lab kits and to then analyze the science practices, crosscutting concepts, and constructivist supports of these physical labs. Van Joolingen et al. (2007) argue that a blend of virtual and physical labs may be best for students. Future research should investigate the physical lab kits that students engage with using their LMS.

A limitation of this study is that as a non-hermeneutic approach (Schreier, 2012) whose goal was to describe the virtual labs, the cumulative whole of science processes that students have the potential to experience through engaging in science practices is not explained or constructed. Future research could look specifically at the science practices as a whole and work with students to see how they conceptualize their experience of science from working with these practices (i.e. – a process or a distinct series of steps). This research line could then accomplish questions such as what are the levels of model construction/use seen in virtual science labs or how do having argumentation prompts facilitate student construction of justifying arguments using evidence?

While research that investigates the effectiveness of virtual labs should follow the aforementioned trajectory, research that uses students as participants and attends more closely to the classroom setting can look at the outcomes of using the labs. Using experimental designs to look at learning gains, qualitative studies that explore what students feel they learned from the labs, and defined communities that serve to increase communication and collaboration within labs are all worthy next steps. An example of this type of study might be a study that considers how students compose their work related to science practices when they are or are not prompted
to develop these practices. Alternatively, comparative studies of communication embedded in the labs versus communication within a single classroom and the quality of these different communication practices, should be investigated.

Affective components of student learning should be investigated in cyber charter schools just as researchers have studied affect with virtual labs in brick-and-mortar schools. Student attitudes about science are an important predictor of how they feel and perform in science classes. The fact that students do not view virtual labs as favorably as they do physical labs (Zacharia et al., 2008, Raish et al., 2012) suggests the need for further research on how cyber charter-school students feel about their laboratory experiences. The relationship between student attitudes and the types of science lab used, if any, would help determine which virtual lab software students prefer and why.

Finally, three cyber charter schools did not have purchased curricula as Moore & Kearsley (2011) state is common practice in these schools. Because some of the curriculum for each of these schools is teacher-designed and some is purchased, an interesting study may be to investigate how teacher ownership of the curriculum impacts students’ perceptions of investing time in completing the labs, as well as teachers’ perceptions of their identifies as valued teachers in the cyber charter schools.

Conclusion

The goal of qualitative content analysis is to pay “attention to unique themes that illustrate the range of the meanings of the phenomenon” (Zhang & Wildemuth, 2009, p. 2). This study met this goal by showing the variety of virtual science labs that students in cyber charter schools complete. The aim of creating ‘thick and rich descriptions’ (Geertz, 1978) of the virtual science labs used in cyber charter schools as also met. This study was motivated by my
experiences of teaching science to middle-school students in the online environment and it is situated in the larger body of research on science labs (Hoffstein & Lunetta, 2004), virtual science labs (Balamuralithara & Woods, 2008; Pyatt & Sims, 2011), and constructivist learning environments (Jonassen, 1999; Wilson, 1996; Zumbach et al., 2006). Challenges faced in this study include discovering that some cyber charter schools did not engage students with any sort of science labs and other cyber charter schools exclusively used physical at-home science kits. The research questions could have shifted had more schools not used virtual labs. One of the labs analyzed blended physical and virtual experimentation. The study contributed knowledge to the field through its guiding research questions, which focused not on content but on science practices and crosscutting concepts in virtual science software and which were contextualized in Pennsylvania cyber charter schools. This study contributes new knowledge because other studies of virtual labs focus on content (see Klahr et al., 2007; Pyatt & Sims, 2011), while this study focuses on the science practices and crosscutting concepts.

A practical implication of this study for designers of virtual labs is that the designers can see what concepts or supports are and are not present in virtual labs and possibly design labs with these supports present. Tables 4.5 and 4.6 presents the markers of science practices, crosscutting concepts, and constructivist learning environments and constructivist design features that were seen in these virtual labs. The structures and descriptions of the virtual labs analyzed here suggest that there are commonly missing features among the labs that relate to certain practices such as engaging in arguments or communication results. The tendency to implicitly express crosscutting concepts was also seen in the labs. Quinn et al. (2012) stress the importance of making these crosscutting concepts explicit. The interesting relationship between ill-structured problem-solving, scaffolds, supports, independence, and confounding variables is a potentially
important finding from the study’s look at constructivist supports. The methodology in this study relates to Chen’s (2010) work on PhET virtual labs and Kesidou and Roseman’s (2002) Project 2061 analysis of middle-school science curriculum. This study contextualized a variety of virtual labs within the cyber charter-school learning environment.

This showed the variety of virtual labs and contexts within different cyber charter schools. Targeting cyber charter schools within one state ensured that all of the cyber charter schools followed the same policies from the state. Selectively analyzing virtual labs allowed for a focus on labs through one modality that prompted similar decisions to be made about design. Interviewing teachers produced themes related to the labs’ deliver, as well as the role of various features in the environment in which students learn, such as parental involvement, communication with teachers, and learning expectations. The implementation of online learning within K-12 classrooms should come with studies assessing the quality of the curriculum that students are using. Science/engineering courses with labs are currently being added to the higher-education online environment. The science courses that middle-school students are taking are in need of analysis due to the specific features they have to promote students’ learning. This study investigated the labs, but the other parts of the curriculum should also be analyzed with the findings from these labs in mind.

Throughout history, there have been efforts to curtail the importance of teachers through one-way technologies. While improvements in the virtual science lab are undoubtedly welcome, the teacher remains fundamentally important in the online learning environment (Maor, 2003). It is my intention that as a result of this study, teachers will be better able to tailor their instruction to meet the students where the labs currently do not. This research showed that none of these labs
teach students everything they should know and that the teacher can tailor educational experiences around these labs in ways that address the gaps of the labs.

In summary, this study does not make claims about what students are learning from the virtual labs or how the design of the labs supports or inhibits student learning. Rather, this is an exploratory study that establishes new and substantial knowledge in describing what is in the virtual labs that students are doing and how teachers use these virtual labs. This study is significant because it looked at the labs being used in cyber charter schools. No prior studies have explored the labs used in cyber charter schools or how the unique learning environment of cyber charter schools can impact the findings from this study. Moore & Kearsley (2011) emphasize looking at the system of distance education. The system that these students are experiencing school in is different than that of brick-and-mortar school students and deserves purposeful thought when structuring the curricula sequence for students in cyber charter schools.

I am hopeful that the emerging findings of this study will inspire new studies and the consideration of different features that have the potential to impact cyber charter-school students’ learning. The focus on science practices and crosscutting concepts in virtual labs will ideally be combined with the core ideas and content that have been focused on in other studies (see Pyatt & Sims, 2011) to consider how virtual labs are engaging students with core ideas through crosscutting concepts and science practices as advocated by the NGSS.
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Appendix A

Recruitment Email

Hello,

My name is Victoria Raish and I am currently completing my dissertation at Penn State. I am doing a media analysis of the virtual science lab software used in cyber charter school. The reason I am doing this is because scientific inquiry is very important for a well-prepared student to become a prepared citizen and there is not a lot known on virtual labs used in a distance based environment with middle school students. For this study I would need access to the virtual lab software that students are using at the middle school level. In addition, I believe that it is important to gain the perspective of teachers who are using this software with their instruction to gain a more holistic understanding of how the science virtual labs are being used in class. Therefore, I would also like to conduct one brief (30 minutes to an hour) interview with a middle school science teacher (biology/life science) regarding their perceptions of inquiry. I have IRB approval for this study and would be collecting the data next fall with the completion of my dissertation expected spring 2016.
Appendix B

Dissertation Executive Summary

This dissertation employs a media analysis qualitative methodology in combination with semi-structured interviews to greater understand the laboratory experiences that are presented to middle school students in cyber charter schools. The rationale behind this topic is that cyber charter schools are an important innovative piece of the educational landscape in Pennsylvania and several thousand students are enrolled in these schools. In addition, scientific inquiry is considered an important competency for students to achieve to help them in their educational careers. Scientific literacy is also an important component of being an aware citizen. Since students in cyber charter schools receive the vast majority of their instruction from a distance the curriculum and labs they are using takes on an even more integral role than it does in traditional brick-and-mortar schools and are likely to have greater variations than in traditional face-to-face classrooms. There has been quantitative research on cyber charter schools but the qualitative research is lacking. I previously conducted a pilot qualitative phenomenographical study regarding how students perceive their virtual labs in a hybrid charter school. This only increased my interest in the topic which stems from me teaching science virtually. The goal of this study is to see if and how the labs used at cyber charter schools in Pennsylvania give students the opportunity to learn science practices, crosscutting concepts, and core ideas from the Next Generation Science Standards. These labs will be evaluated according to a model of inquiry developed from the Next Generation Science Standards and learning supports from constructivist learning theory. My methods and requirements for achieving this goal are to access the labs and software from the student view and go through the lab as a student would (with any necessary explanation or supplementation from the instructor). As I am doing this I will conduct the content analysis on the labs to identify markers from the NGSS in the labs. In addition, I would interview a teacher who delivers these labs. This interview will take between 30-40 minutes. The goal of this interview is to understand the context in which the labs are completed by the students and also to gain the perspective of the teacher on the inquiry presented in these labs. The reason I want to interview teachers is to triangulate the data, gain the perspective of users of the labs, and to understand the context of students. My research questions are as follows: Are there potential markers of scientific practices, crosscutting concepts, and core ideas in the labs that students in cyber charter schools use? What are the variations in how cyber charter schools implement virtual labs? What constructivist supports are built into the curriculum to support students in their labs?
Appendix C

*SPP Performance Profile*

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Description</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic Cyber charter school C</td>
<td>Includes: standardized assessment (PSSA or Keystone) performance, industry standards-based competency assessments, grade 3 reading proficiency, and SAT/ACT college</td>
<td>40%</td>
</tr>
<tr>
<td>Academic Growth/PVAAS</td>
<td>Measures school’s impact on academic progress of groups of students from year to year</td>
<td>40%</td>
</tr>
</tbody>
</table>
| Closing the Cyber charter school C Gap: Two Elements | All students: All student scores are used to define how well a school is making progress toward proficiency for all students  
Historically Underperforming Students: Scores are used to define how much progress a school is making toward proficiency | 5%     |
| Other Academic Indicators                      | Assesses factors that contribute to student cyber charter school C (e.g., graduation rate, promotion rate, attendance rate)                                                                                  | 10%    |
Appendix D

Questions for Teachers

1. How frequently do the students complete virtual labs?

2. Do they complete the virtual labs synchronously or asynchronously?

3. Do they regularly interact with you or their peers when completing these virtual labs?

4. Can they contact you while they are completing the labs if they have a question?

5. What do you do to support the students in the virtual labs?

6. Do you have challenges or issues have you faced in instructing students in the virtual labs? If so, what are they?

7. Have you done anything to work around challenges or issues that you encountered in instructing the virtual labs?

8. Can you describe the typical curriculum sequences that precedes and comes after the virtual labs?

9. Do students ever collaborate on the virtual labs?

10. Do students get a chance to communicate or share their findings?

11. Do you ever talk about the virtual labs during your class?

12. What are some of the student response to completing the virtual labs?

13. What virtual labs software do you use in class?
Appendix E

Thematic Map – Teacher Interviews
Appendix F

Example ExploreLearning Worksheet

Name: ______________________________________  Date: ______________________

Student Exploration: Evolution: Natural and Artificial Selection

**Vocabulary**: artificial selection, breed, chromosome, evolution, fitness, genotype, mutation, natural selection, phenotype

*[Note to teachers and students: This Gizmo™ was designed as a follow-up to the Evolution: Mutation and Selection Gizmo. We recommend doing that activity before trying this one.]*

**Prior Knowledge Question** (Do this BEFORE using the Gizmo.)

This illustration from an old textbook shows some of the over 150 different dog *breeds* that can be seen around the world today. How do you think all of these different breeds were developed?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
Gizmo Warm-up

Dog breeds and other varieties of domesticated animals were developed through artificial selection. Over many generations, breeders selected which animals to mate in order to select for desired traits. The Evolution: Natural and Artificial Selection Gizmo allows you to try your hand at breeding insects with a variety of colors. To begin, select the Artificial selection option.

1. Drag the 10 insects into the breeding alcoves on the left side of the Gizmo.
   A. How many breeding pairs are there? ____________________
   B. How many offspring are produced? ____________________

2. Circled insects have mutations, or changes to their DNA. How many of the offspring insects in this generation have mutations? ____________________

| Activity A: | Get the Gizmo ready: |
| Genotype and phenotype | • Select Natural selection. |

Question: How are genes inherited and modified over many generations?

1. Observe: The fitness of an insect is a measure of how well it is adapted to its environment.
   A. What is the initial Average fitness of these insects? ____________________
   B. Click Play ( ), and observe the simulation for several generations. What occurs in each generation? ________________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________
C. Increase the Sim. speed by one level. Click Pause after 30 generations. What is the Average fitness now? ____________________________

2. **Analyze:** Set the Sim. speed to its slowest level. Click Play, and then Pause when the offspring appear. Choose a pair of parents in which both parents have a different color.

A. Move your cursor over a parent insect. The genes that control color make up an insect’s **genotype**, while its actual color is its **phenotype**. Fill in the genotypes and phenotypes of each parent below.

<table>
<thead>
<tr>
<th>Parent 1</th>
<th>Parent 1</th>
<th>Parent 2</th>
<th>Parent 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>genotype</td>
<td>phenotype</td>
<td>genotype</td>
<td>phenotype</td>
</tr>
<tr>
<td>Red = __________</td>
<td>Green = __________</td>
<td>Red = __________</td>
<td>Green = __________</td>
</tr>
<tr>
<td>Blue = __________</td>
<td>Blue = __________</td>
<td>Blue = __________</td>
<td>Blue = __________</td>
</tr>
</tbody>
</table>

Now list the genotypes of each of the four offspring below.

<table>
<thead>
<tr>
<th>Offspring 1</th>
<th>Offspring 2</th>
<th>Offspring 3</th>
<th>Offspring 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Activity A continued on next page)
Activity A (continued from previous page)

3. **Explain**: Each rod-shaped structure is a **chromosome**. Real chromosomes contain hundreds or even thousands of genes. The simplified chromosomes shown in this Gizmo only contain genes that determine the insects' colors.

How are the chromosomes of the offspring related to the chromosomes of the parents?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

4. **Investigate**: Any insect that has a mutation will be circled. Place your cursor on an insect with a mutation to examine its genotype. (If there are none in this generation, click **Play** and then **Pause** when a mutation appears.)

   A. Examine the genotype of the mutated insect as well as the genotypes of its parents to determine what the mutation is. What new gene appeared? __________________

   B. Do you think this mutation is helpful, harmful, or neutral for the insect? Explain.

       ______________________________________________________________________

   C. Click **Play**, and then click **Pause** after the birds have finished eating. Did the mutated insect survive? ____________________________

5. **Observe**: Increase the **Sim. speed** by two levels. Click **Play**, and wait for a while. What occurs as time goes by? ______________________________________________________

       ______________________________________________________________________
6. **Explain:** In wild populations, *evolution* is often caused by *natural selection*. Based on what you have observed, how does natural selection occur?

_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________
Activity B: Artificial selection

Get the Gizmo ready:
- Select Artificial selection.
- Set the Mutation rate to 2.0.

Question: How can a species be changed through artificial selection?

1. Set a goal: In this activity, your goal is to develop insects that are any color you would like.

   What color do you want your insects to be? ____________________________________________

2. Make a plan: Follow the directions in the Gizmo to produce five generations of insects.

   A. How would you describe the process of artificial selection? ________________________
      ________________________________________________________________
      ________________________________________________________________
      ________________________________________________________________

   B. How will mutations be useful in achieving your goal color? _______________________
      ________________________________________________________________
      ________________________________________________________________
      ________________________________________________________________

   C. What strategy will you use to produce insects of your desired color? _____________
      ________________________________________________________________
      ________________________________________________________________
      ________________________________________________________________

3. Run Gizmo: Use the Gizmo to produce insects that match your goal color. (This will take patience!) When you are satisfied, click the camera (_CAMERA_) to take a snapshot. Right-click the image and choose Copy Image, then paste the snapshot into a blank document that you will turn in with this worksheet.
How many generations did it take for you to develop your insects? ____________________

4. **Compare**: If possible, compare your insects to the insects developed by your classmates.

What different colors of insects can be developed using artificial selection? ______________

________________________________________________________________________

________________________________________________________________________

(Activity B continued on next page)
Activity B (continued from previous page)

5. **Explain:** One of the tallest dog breeds is the Great Dane, which stands over a meter tall. One of the shortest is the Pomeranian, which stands about 20 centimeters tall. Based on what you have learned about artificial selection, how were these two breeds developed?

_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

6. **Collect data:** Use the Red, Green, and Blue sliders to match the Background color as closely as possible to phenotype of the insects. Select Natural selection.

Click Play, and then click Pause when the Average fitness first exceeds 90%. Record the number of generations in the table below, and then repeat for a total of five trials.

<table>
<thead>
<tr>
<th>Trial</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of generations to achieve 90% fitness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. **Calculate:** Add up the number of generations and divide by five to find the mean number of generations required to reach at least 90% fitness. Fill in the last column of the table.

8. **Analyze:** Which process tends to occur more quickly, natural selection or artificial selection? Why do you think this is so?
9. **Summarize:** How are the processes of natural selection and artificial selection similar? How are they different? If possible, discuss your answer with your classmates and teacher.
Activity C: Mutation rates

Get the Gizmo ready:

- Click Reset ( ). Be sure Natural selection is selected.
- Set Red to 100, Green to 255, and Blue to 50.

<table>
<thead>
<tr>
<th>Mutation rate</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Question: How does the mutation rate affect a population’s ability to adapt to its environment?

1. **Gather data:** Change the Mutation rate to 0.1 and the Sim. speed slider to its lowest setting. Click Play, and then click Pause when the offspring appear. Record the number of mutations (circled offspring), and then repeat for two more trials. Do this for each mutation rate listed in the table, then calculate the mean number of mutations for each mutation rate.

<table>
<thead>
<tr>
<th>Mutation rate</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   How does the mutation rate relate to the number of mutations in each generation?

   ____________________________________________________________________________

   __________

2. **Form hypothesis:** How do you expect the rate of mutations to affect the ability of the bug population to adapt to its environment?

   ____________________________________________________________________________

   ____________________________________________________________________________

   __________

3. **Gather data:** Click Reset. Set the Mutation rate to 0.1, and move the Sim. speed slider to a faster setting. Click Play, and then click Pause when the Average fitness
is 90% or greater. Record the number of generations required to reach 90% fitness in the table below.

<table>
<thead>
<tr>
<th>Mutation rate</th>
<th>Number of generations to 90% average fitness</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
</tr>
<tr>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Activity C continued on next page)
Activity C (continued from previous page)

4. **Analyze:** How does the mutation rate affect the speed at which a population adapts to its environment?
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________

5. **Think and discuss:** You may have noticed that above a certain mutation rate the time required for a population to adapt to its background may increase. Why do you think this is so? If possible, discuss your answer with your classmates and teacher.
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________

6. **Apply:** Scientists doing artificial breeding experiments often use radiation or other methods to increase the mutation rate. Why is a high mutation rate useful?
   ______________________________
7. **Investigate:** Use the Gizmo to develop a population of insects that are well adapted to their environment. *(Average fitness is above 90%).* Change the **Mutation rate** to 0.1, and run the simulation. Then, observe the population with a **Mutation rate** of 10.0.

A. What do you notice?

B. If a population is already well-adapted to its environment, will most mutations be helpful or harmful? Explain.
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