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## The Effect of Scaffolded Strategies on Content Learning in a Designed Science Cyberlearning Environment

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THE EFFECT OF SCAFFOLDED STRATEGIES ON  
CONTENT LEARNING IN A DESIGNED SCIENCE  
CYBERLEARNING ENVIRONMENT

by

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A dissertation submitted in partial fulfillment  
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August 2013



## THE GRADUATE COLLEGE

We recommend the dissertation prepared under our supervision by

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Cyberlearning Environment**

is approved in partial fulfillment of the requirements for the degree of

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**August 2013**

## **Abstract**

### **The Effect of Scaffolded Strategies on Content Learning in a Designed Science Cyberlearning Environment**

by  
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Scientific inscriptions—graphs, diagrams, and data—and argumentation are integral to generating and communicating scientific understanding. Scientific inscriptions and argumentation are also important to learning science. However, previous research has indicated that learners struggle to understand and learn science content represented in inscriptions. Furthermore, when learners engage in argumentation, learning science content becomes secondary to the learning of argumentation skills. This design-based research study is nested within the larger effort to inform the design and development of the 5-Featured Dynamic Inquiry Enterprise design framework (5-DIE) for cyberlearning environments and to advance theory associated with the difficulties learners have with scientific inscriptions and the consequences related to using argumentation to learn science content.

In an attempt to engage participants in the process of learning science content with scientific inscriptions and argumentation, two learning strategies were embedded in

a 5-DIE lessons. The two learning strategies evaluated in this study were (1) *self-explanation prompts* paired with a scientific inscription and (2) *faded worked examples* for the evaluation and development of scientific knowledge claims. The participants consisted of ninth and tenth grade students (age: 13-16 years; N=245) enrolled in one of three state-mandated biology courses taught by four different teachers.

A three factor mixed model analysis of variance (ANOVA) with two between factors (self-explanation prompts and faded worked examples) and one within factor (pre, post, delayed post-test) was used to evaluate the effects of the learning strategies on the acquisition and retention of domain-specific content knowledge. Both between factors had two levels (with & without) and are described by the following experimental conditions: (1) control condition (general prompts), (2) self-explanation condition, (3) faded worked examples condition, and (4) combined condition with both self-explanation and faded worked examples. Acquisition and retention of content knowledge was assessed with a 17-item multiple-choice, researcher-developed content knowledge test.

Results indicated that self-explanation prompts and faded worked examples learning strategies did not influence acquisition and retention of science content in a positive (i.e., learning) way. Based on the finding of this study, it may be concluded that the use of general prompts is as effective as self-explanation prompts and faded worked examples for scaffolding learner engagement with scientific inscriptions and argumentation. Furthermore, the finding indicated additional research is warranted evaluating the generalizability of scaffolds from college to pre-college populations.

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Here's to the crazy ones.  
The misfits. The rebels. The troublemakers.  
The round pegs in the square holes.  
The ones who see things differently.  
They're not fond of rules.  
And they have no respect for the status quo.

You can praise them, disagree with them, quote them,  
disbelieve them, glorify or vilify them.  
About the only thing you can't do is ignore them.  
Because they change things.  
They push the human race forward.

And while some may see them as the crazy ones, we see genius.  
Because the people who are crazy enough to think they can change the world - are the  
ones who do.

Rob Siltanen & Ken Segall  
Apple Commercial – “Think Differently”

Here's to the “crazy ones” in my life that guided me forward as well as walked beside me through this journey. There were more times than I would like to admit where I did not believe I could take another class, read another article, or write another word. Yet with every obstacle I encountered my family and friends were there to help and support me, having more faith in my abilities than I ever have had. It has been an amazing experience to realize that those who are the closest to me—family and friends—were kindred spirits in the world of “crazy ones.” I believe that my loved ones have been shaping me for this journey all along. On while on this journey I was fortunate to be teamed up with professional “crazy ones,” who have not only traveled this path but have devoted their life to help others along it. Part of this course of study has been about my academic work but, upon reflection, another part of this journey was about what it means

to experience these educators as role models, people who have knowledge, and experience, and also a willingness to help those with similar hopes and dreams.

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## **Chapter 1 Introduction to the Study**

The United States is falling behind in national and international comparisons of competencies related to science literacy. In 2009, the National Assessment of Educational Progress (NAEP), also known as the Nation's Report Card, found that approximately 65 percent of 4th graders, 70 percent of 8th graders, and 79 percent of 12th graders were not proficient in science (National Center for Education Statistics [NCES], 2009).

Internationally, U.S. students are also behind those from the highest performing nations. Only 10 percent of U.S. 8th graders achieved the advanced international benchmark in science on the Trends in International Mathematics and Science Study (TIMSS), compared with 32 percent from Singapore and 25 percent from China (Committee on Highly Successful Schools or Programs in K-12 STEM Education, & National Research Council [NRC], 2011). According to the National Science Education Standards (NSES) (NRC, 2000), excellence in science education is based on the premise that science is for all students regardless of age, gender, cultural or ethnic background, yet the results from the NAEP and TIMSS assessments indicate that this goal is not being achieved.

These deficiencies are being addressed by the national focus on Science, Technology, Engineering, and Mathematics (STEM) education that calls for increasing STEM literacy for all students, regardless of their future career choice. STEM literacy is important because personal and societal decision-making requires scientific and technological understanding (NRC, 2011). The importance of STEM literacy is further emphasized in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (Framework) (NCR, 2011), which is the foundational document for the development of the Next Generation Science Standards. This document

lays out the core ideas and practices in science that students should master in preparation for college and careers and highlights the need for individuals who have the ability to not only accurately and effectively interpret and construct science-based ideas (Cavagnetto, 2010), but also possess the ability to participate in science-based social and personal decision-making (Norris & Philips, 2003). However, the development of a science literate citizen is facilitated, in part, through the school science education experience. Although national documents describe the need for a scientifically literate citizenry, Martinez and Peters Burton (2011) state, “Science teaching in the USA is turning off many students to scientific careers, threatening self-efficacy, engendering misconceptions about that natural world, and conveying wrong ideas about the nature of the scientific enterprise,” (p.17).

Recent trends suggest that educators are turning to cyberlearning, or “learning that is mediated by networked computing and communications technologies” (NSF, 2008 p. 10), to promote the development of science literate students. Research indicates that technology can have an effect on our capacity to teach students in ways that promote science literacy (Allen & Seaman, 2008). Beyond developing science literate students, cyberlearning can provide technology-enhanced scaffolds that allow learners to engage in a task that is beyond their independent abilities. In fact, researchers have evaluated specifically how learner characteristics and contextual conditions in technology enhance learning environments are affected by such scaffolding interactions (Kim & Hannafin, 2011). Furthermore Sharma and Hannafin (2007) have also evaluated how learner characteristics and contextual conditions in technology enhanced learning environments (TELE) are affected by scaffolding interactions.

Researchers have developed Web-based guided activities, prompting, visualization and modeling tools, as well as communication tools designed to address acquisition of content knowledge as well as develop self-regulated learning (Linn, Clark, & Slotta, 2003). For example, several online learning tools have been developed over the past few decades with the aim of engaging and scaffolding students' science education experiences, such as the Web-Based Inquiry Science Environment (WISE), the Biology Guided Inquiry Learning Environment (BGuILE), and the Physics Education Technology Project (PhET) (e.g., Linn, Bell, & Davis, 2004; Reiser, Tabak, Sandoval, Smith, Steinmuller, & Leone, 2001; Scardamalia, 1989; Stern, 2000). Yet, technology is rarely used to address the diverse needs of learners such as (Kim & Hannafin, 2011). The design and development of cyberlearning environments should account for the diverse needs of learners and affect their understanding in ways that promote critical thinking, problem-solving, and science literacy.

**National Science Education Standards.** It has been almost twenty years since the national movement towards inquiry-based science education began with the National Science Education Standards (NSES) (NRC, 2000; 1996). The NSES was developed as a way to address the need for critical thinking, problem-solving, and the development of science literacy in science classrooms. Yet inquiry-based instruction facilitated through technology has rarely been used to promote critical thinking in the classroom setting (Kim & Hannafin, 2011). Addressing the issue of using inquiry as the recursive, reflective, and collaborative learning strategy in a cyberlearning environment is not as simple as adopting inquiry-based methods (discussed in Chapter 2) (Kern, Crippen, & Skaza, in press). The 5-Featured Dynamic Inquiry Enterprise (5-DIE) design framework

has been developed to address the need for an inquiry-based cyberlearning environment. 5-DIE is designed to promote critical thinking, problem-solving, and science literacy by incorporating inquiry with cyberlearning, while acting as a design framework that supports the existing practices of teachers in secondary schools (Kern *et al.*, in press). The 5-DIE design framework provides comprehensive guidelines and a wide range of scaffolds that support the enactment of inquiry-based instruction in cyberlearning environments. 5-DIE will be discussed in more detail in the section Design Goals for 5-Featured Dynamic Inquiry Enterprise in Chapter 2.

This study is situated within a larger effort to inform the design and development of the inquiry-based 5-DIE design framework for science cyberlearning environments. The intent of this study is to inform the instructional design of cyberlearning environments that are meant to overcome the concerns related to using scientific statements or claims to learn science content and the difficulties learners have with scientific representations (e.g., graphs, diagrams, and data) (Bowen & Roth, 2002). Currently, scaffolding meaningful engagement in the process of learning with scientific claims and scientific representations in an *in situ* cyberlearning environment is an emerging paradigm with few published studies. The studies that have been done about these topics have been done in research settings or with select populations of student, but what is needed is information about how students use these scaffolds to learn in a classroom environment.

## **Purpose**

The purpose of this study was to advance current educational theories related to difficulties learners have understanding and using scientific inscriptions and

argumentation to learn science content by analyzing the effect of two learning strategies embedded in a 5-DIE lesson on the acquisition and retention of science content knowledge for ninth- and tenth-grade students enrolled in state-mandated biology courses at a large, suburban high school in the southwestern United States. Furthermore, the outcomes of this study are meant to inform the innovation of the 5-DIE design framework and understanding to scaffold in cyberlearning environments.

The first learning strategy, faded worked examples, is designed to meaningfully engage learners in the evaluation and development of a scientific claim statement. Faded worked examples are a progression of detailed problem solutions in which the process used to solve a problem is made explicit to a learner. During this progression, the problem solutions and explanations are systematically removed as learners proceed through the series and develop their problem solving skills (Crippen & Earl, 2007). In the current study the faded worked example learning strategy was designed to engage learners in the critical evaluation of several expert claim statements in which the development of a claim statement is modeled. Over the series of four expert claim statements, steps or components of the claim statement are removed (i.e., faded), thus requiring the learner to complete the remaining steps. In the final step of the learning strategy, the learners provide their own claim statement.

The second learning strategy, self-explanation prompts paired with scientific inscriptions, was designed to shift the mental effort (i.e. cognitive load) from superficial engagement with scientific inscriptions (e.g., graphs, diagrams, and data) to meaningful engagement by providing sentence starter prompts designed to promote reflective self-explanation. This learning strategy was designed to reduce passive engagement when

learning with scientific inscriptions and it promotes reflective self-explanation of the content represented in the scientific inscription.

In addition, a relationship is predicted between engaging with a scientific inscription and generating a claim statement. The two learning strategies may have an additive effect on students' learning. This relationship may be significant for understanding the science content presented in a lesson.

### **Research Questions and Hypotheses**

The following research questions guided this study:

1. What is the effect of learning with inscriptions paired with self-explanation prompts during evidence collection in a 5-DIE lesson on the acquisition and retention of domain-specific content knowledge?
2. What is the effect of faded worked examples for the evaluation and development of scientific knowledge claims during a 5-DIE lesson on the acquisition and retention of domain-specific content knowledge?
3. Is there an effect related to inscriptions paired with self-explanation prompts and use of faded worked examples for the scientific knowledge claims on the acquisition and retention of domain-specific content knowledge?
4. How can the results of this study contribute to the further innovation of 5-DIE?

Using a quasi-experimental design, participants were assigned to one of four conditions: a 5-DIE lesson that included neither of the learning strategies (control condition), a 5-DIE lesson that included a scientific inscription paired with reflective self-

explanation prompts (self-explanation condition), a 5-DIE lesson that included faded worked examples for the evaluation and development of scientific knowledge claims (faded worked example condition), and a 5-DIE lesson that included both learning strategies (combined condition). This design was used to assess the effect of self-explanation prompts, the effect of faded worked examples, and the effect of the combination of the both learning strategies on the acquisition and retention of content knowledge. Presented next are the research hypotheses for each condition in the experimental design.

**Research hypothesis related to self-explanation prompts condition.**

Participants in the self-explanation prompt condition will outperform the control condition on the acquisition and retention of domain-specific content knowledge.

**Research Hypothesis related to faded worked examples condition.**

Participants in the faded worked example condition will outperform the control group on the acquisition and retention of domain-specific content knowledge.

**Research Hypothesis related to the potential interaction effect.** Participants in the combined condition, self-explanation prompts and faded worked example condition, will experience an interaction effect and will outperform the control group, the self-explanation prompts, and faded worked examples conditions on the acquisition and retention of domain-specific content knowledge.

**Theoretical Framework**

Design-based research (DBR) is the theoretical framework guiding this study (Barab & Squire, 2004; Edelson, 2002; Wang & Hannafin, 2005). Wang and Hannafin (2005) define DBR as, “a systematic but flexible methodology aimed to improve

educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories” (p. 6). Historically, DBR has two primary goals: 1) to understand how people learn in settings that include the complexities and dynamics associated with the practices of teaching and learning and 2) to design research-based methods to ensure that meaningful learning occurs in these environments (Brown, 1992; Edelson, 2002; Wang & Hannafin, 2005). Wang and Hannafin (2005) describe the characteristics of design-based research as "(a) pragmatic; (b) grounded; (c) interactive, iterative, and flexible; (d) integrative; and (e) contextual" (pp.7-8). In the following sections each characteristic of DBR is explained and how this study exemplifies each characteristic is detailed.

**Context.** The complex and dynamic nature of a classroom includes variables that are often times not measurable or predictable. Barab and Squire (2004) emphasize that context is a core part of educational research and “not an extraneous variable to be trivialized” (p. 3). Design-based research acknowledges the complexity as well as the many variables that are associated with a natural learning context, so the research focuses on identifying and keeping one or two variables constant (Barab & Squire, 2004). They also assert that learning, cognition, knowing, and context cannot be treated in isolation. Therefore, DBR strives to systematically understand and predict how learning occurs in a naturalistic setting described by Barab and Squire (2004) as, “occur[ing] in the buzzing, blooming confusion of real-life settings where most learning actually occurs” (p. 4).

The real-life, chaotic, naturalistic setting of a large, urban, comprehensive high school was the context of this study. More than 630 students participated in the lessons



designed for this study, 367 of those consented/assented to participate, but only 245 completed all three data collection sessions and were classified as research participants. The four teachers whose classes were used in the study had no less than 37 students per class. Working in the natural setting of high school classrooms is a complex endeavor. Over the course of the study, the computer network at the school was unavailable at multiple times, a fire drill occurred, and a threat of violence at the school resulted in a high number of absences on the day of the posttest. Teachers engaged their students in the lesson and were given the freedom to meet the individual needs of those students. In this study the only variables held constant were the independent variables: self-explanation prompts paired with scientific inscriptions learning strategy and the faded worked example for the development and evaluation of scientific knowledge claims learning strategy.

**Grounded.** Educational design problems are described as messy (Golding *et al.*, 2009) or ‘wicked’ by nature (O'Neill, 2012). Wicked problems are deemed thus because “they are never finally solvable; they are contingent problems of deciding what to do that require resolution over and over again” (Marback, 2009, p. 399). Also, the solutions and explanations to wicked problems are dependent on the worldview and the theoretical perspective of the designer (Golding *et al.*, 2009). Thus, it is essential for design-based researchers to provide sufficient and appropriate detail related to the theory that informs their design decisions. Grounding the design in theory allows other researchers to generate alternative explanations for the study’s outcomes, while possibly contributing to future design decisions (O'Neill, 2012).

In an attempt to ensure that the design results in meaningful learning in an often chaotic environment, DBR was used to provide a framework for systematically modifying aspects of a designed intervention that is grounded in theory, allowing the researcher to both test and generate new theory associated with teaching and learning (Barab & Squire, 2004). Design-based research that ignores prior work or disregards relevant theory cannot inform the practices of teaching and learning (O'Neill, 2012). The specific theory grounding the 5-DIE design framework is the NSES essential features of inquiry (NRC, 2000), and the design decisions related to the learning strategies developed for this study are built on cognitive load theory (Sweller, 1988).

**Inquiry-based instruction.** The theory grounding the design and development of the 5-DIE design framework is the five essential features of inquiry or inquiry-based instruction (NRC, 2000). This study evaluates the effects of scaffolding meaningful engagement in the process of learning with scientific inscriptions and scientific claims embedded in a 5-DIE lesson. Each of the four conditions implemented in this study are identical, except for the specific learning strategies, self-explanation prompts and faded worked examples, embedded in the initial 5-DIE lesson.

The NSES movement towards inquiry-based science education began as a way to address the need for critical thinking, problem-solving, and the development of science literacy in science classrooms. The catalyst for this movement stems from the federal report, *A Nation at Risk: An Imperative for Educational Reform* (1983). This report, which details the manner in which scientists think about and work to address questions about the natural world, has been proposed as the primary mechanism for learning science (NRC, 2000). The aim of inquiry-based science education is to develop the

necessary inquiry skills and scientific knowledge to inform learners' decision-making associated with scientific issues that are both personal and social.

The National Research Council (NRC, 2000) identifies five essential features of inquiry that are central to inquiry-based instruction in science learning environments:

- 1) Learners are engaged by scientifically oriented questions;
- 2) Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions;
- 3) Learners formulate explanations from evidence to address scientifically oriented questions;
- 4) Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding; and
- 5) Learners communicate and justify their proposed explanations.

These essential features of inquiry are practiced along a continuum ranging from student-centered open inquiry to completely teacher-centered, highly-structured inquiry (NRC, 2000). Open inquiry is characterized by minimal guidance. The learner's success is dependent upon prerequisite knowledge acquired from prior structured experiences (Kirschner, Sweller, & Clark, 2006). Inquiry that is guided or structured reduces learner frustration and increases on task behaviors (Trautmann, MaKinster, & Avery, 2004).

Most students' initial exposure to inquiry practices should be guided. Then, as the learner progresses, they can develop the skills necessary for open inquiry (Flick & Lederman, 2006; Sadeh & Zion, 2009).

**Cognitive load theory.** Cognitive load theory (CLT) serves as the theoretical grounding for both of the learning strategies used in this study, self-explanation prompts

and faded worked examples (Sweller, 2005; Kirschner *et al.*, 2006). CLT is an instructional design theory that has the designer consider the cognitive architecture of the learner when developing learning strategies (Schnotz & Kirschner, 2007). By taking into consideration the cognitive capabilities and limitations of the learner, instructional design can be made to influence learning. CLT explains the relationship that exists between working memory and learning or the development of a schema in long-term memory (Kalyuga, Ayres, Chandler, & Sweller, 2003). The primary claim of CLT is that without considering the cognitive architecture of the learner, the effectiveness of instructional design is likely to be random (Schnotz & Kirschner, 2007). CLT is discussed in greater detail in Chapter 2.

**Interactive, iterative, and flexible.** The process of design in DBR is cyclic and dynamic. The entire process is meant to address an educational need by first making research-based conjectures that are explored through the design, implementation, and evaluation of an intervention, with the results informing theory, future innovations, and the researcher's understanding associated with teaching and learning (Edelson, 2002; Wang & Hannafin, 2005). The educational need addressed in this study involves the difficulties learners have with understanding scientific inscriptions and the implications of using scientific argumentation during the explicit instruction of science content. At the inception of this project, the teachers involved in the implementation of the 5-DIE lesson worked in collaboration with the researcher to determine the content to be taught. The teachers were also involved in the development of the lesson through an iterative design-implementation-redesign process over a two-year period. Furthermore, upon

implementation, the teachers were given the flexibility to make the changes necessary to meet the individual needs of their students.

**Integrative.** Design-based research draws from both quantitative and qualitative methodologies. The use of combined or mixed methodologies provides the opportunity for multiple data sources increasing the objectivity, validity, and applicability of the design framework (Wang & Hannafin, 2004). This study is situated within a larger effort meant to inform the research and development of the 5-DIE design framework for cyberlearning environments. Research, up to this point, has involved a single mixed method study meant to determine the fidelity and describe the usability of 5-DIE (Kern *et al.*, in press). Building from that foundation, this study is a quasi-experimental, three-factor design, with two between factors and one within factor meant to inform design decisions related to the effect of embedded learning strategies on content knowledge. Hence, this study is quantitative in nature, yet it is a single study nested within a larger integrated endeavor.

**Pragmatic.** The pragmatic aspect of design-based research implies that it contributes to the refinement of both theory and practice (Wang & Hannafin, 2005). This study looks to refine the 5-DIE design framework and understand how self-explanation prompts affect learning science content that is represented in scientific inscriptions. It also examines the implications of using faded worked examples to scaffolded scientific argumentation for the explicit instruction of science content and seeks to improve teaching practices. The pragmatic nature of this study looks, in part, to inform future innovations of the 5-DIE design framework as well as contributing to the refinement of

educational theory related to learners' difficulties understanding and utilizing scientific inscriptions and argumentation to learn science content.

### **Significance of the Study**

The nature of this designed-based research includes the refinement of both theory and practice associated with understanding how scaffolds allow a learner to better focus on the science content represented in both scientific inscriptions and argumentation. There are two primary bodies of research that inform this study: 1) learner difficulties in understanding scientific inscriptions and 2) the implications of using scientific argumentation for the explicit instruction of science content. Research indicates that learners passively engage in processing the meaning and content represented in scientific inscriptions (Atkinson & Renkl, 2007). The contribution of this study involves understanding how scaffolding can be used to overcome difficulties learners have with scientific inscription. Specifically, understanding how the use of self-explanation prompts may be used to make explicit the meaning of and content represented in a scientific inscription, which may result in the acquisition and retention of content knowledge.

This study also contributes to what we know about the effect of argumentation as a content learning strategy. Specifically, the study addresses how to scaffold a learner's experience in argumentation with faded worked examples as a way to reduce the learning emphasis on how to argue and increase the cognitive processing of the content. Furthermore, in the tradition of design-based research, the study may have a significant contribution to future innovation of 5-DIE related to scaffolding learner interactions with scientific inscriptions and engagement in argumentation.

## **Chapter 2 Review of the Literature**

### **Introduction**

This study is situated within a larger effort to inform the design and development of the 5-Featured Dynamic Inquiry Enterprise (5-DIE) design framework for cyberlearning environments or learning environments using networked computers to enhance science instruction (NSF, 2008). The research and development of 5-DIE was initiated as a response to the call for an online, inquiry-based, science-learning environment designed to promote critical thinking and problem solving (Kim & Hannafin, 2011). Primarily, the continued research and development of 5-DIE results in innovations to the framework meant to engage learners in inquiry in cyberlearning environments. This larger research endeavor involves an iterative cycle of design, development, implementation, and innovation, which are characteristic of design-based research (Barab & Squire, 2004; Edelson, 2002; Wang & Hannafin, 2005).

The pragmatic nature of this study intends to advance education theories related to the struggles learners have with learning science content associated with scientific inscriptions and argumentation by analyzing the effects of two learning strategies embedded in a 5-DIE lesson on the acquisition and retention of content knowledge of ninth- and tenth-grade biology students.

The first learning strategy evaluated involved the use of faded worked examples to promote learning through the evaluation and development of a scientific claim statement (i.e., evidence, claim, reason) (Toulmin, 1958). Faded worked examples are a progression of detailed problem solutions where the processes used to solve a problem are made explicit to the learner, and the problem solutions and explanations are

systematically removed as the learner proceeds in developing problem solving skills (Crippen & Earl, 2007). In the current study, the faded worked example learning strategy was meant to engage learners in the critical evaluation of multiple claim statements developed by an expert.

The second learning strategy involved the use of self-explanation prompts paired with scientific inscriptions. Self-explanation prompts are presented as sentence starter prompts used to elicit self-reflection through a structured, explicit start to a constructed response. In the current study, self-explanation prompts are designed to shift mental effort (i.e., cognitive load) from superficial engagement with scientific inscriptions to meaningful learning by scaffolding learners in a reflective statement that is meant to promote learning of the content represented in the inscription. Finally, the two learning strategies were combined to determine any combined effect on learning. This study intends to advance current educational theories associated with learners' difficulties understanding and using scientific inscriptions and argumentation to learn science content. In addition, this study intends to determine whether these learning strategies significantly affect the acquisition and retention of content knowledge beyond the current 5-DIE design framework—the results thereby informing future 5-DIE design decisions.

### **Research Questions**

- 1) What is the effect of learning with inscriptions paired with self-explanation prompts during evidence collection in a 5-DIE lesson on the acquisition and retention of domain-specific content knowledge?



- 2) What is the effect of faded worked examples for the evaluation and development of scientific knowledge claims during a 5-DIE lesson on the acquisition and retention of domain-specific content knowledge?
- 3) Is there an effect related to inscriptions paired with self-explanation prompts and use of faded worked examples for the scientific knowledge claims on the acquisition and retention of domain-specific content knowledge?
- 4) How can the results of this study contribute to the further innovation of 5-DIE?

### **Theoretical Framework**

The theoretical framework guiding this study was design-based research (DBR) (Barab & Squire, 2004; Edelson, 2002; Wang & Hannafin, 2005). DBR is primarily concerned with understanding how people learn in the complex and dynamic settings associated with the practices of teaching and learning and designing research-based methods to promote meaningful learning in these environments (Brown, 1992; Edelson, 2002; Wang & Hannafin, 2005). DBR is characterized by the naturalistic context as well as the grounded nature of design decisions (Wang & Hannafin, 2005). Grounding design decisions allows the researcher to make design decisions for the chaotic, real-world context of a high school science classroom based on theory that has often been generated under experimental conditions. DBR provides a framework for systematically modifying aspects of theory-based design, allowing the researcher to both test and contribute to theory associated with teaching and learning (Barab & Squire, 2004).

In the following section, the design goals for 5-DIE are identified and described, cognitive load theory is discussed as the theoretical grounding that guides decisions related to the design of the faded worked example and self-explanation prompt learning strategies, and the research related to faded worked examples and self-explanation prompts are presented.

### **Design Goals for 5-Featured Dynamic Inquiry Environment**

The research and development of the 5-DIE design framework comes as a response to the need for an online, inquiry-based, science-learning environment meant to promote critical thinking, problem solving, and scientific literacy. This study is nested within the larger effort to inform the design and development of the 5-DIE design framework for cyberlearning environments and to advance theory associated with the difficulties learners have with scientific inscriptions and the consequences related to using argumentation to learn science content. Specific design goals related to 5-DIE include the development of an authentic scientific inquiry learning experience, addressing and implementing scientific practices, developing the skills and abilities associated with the evaluation and development of scientific inscriptions, and scaffolding collaborative argumentation in a way productive to the acquisition and retention of scientific content knowledge, all within a cyberlearning environment. Each of these design goals will be discussed in the next sections.

**Inquiry.** The 5-DIE design framework is grounded in the NSES's essential features of inquiry (Kern *et al.*, in press) and is designed as a framework for the guided development of inquiry skills and abilities, as well as science content and skills of self-regulation of all learners. The framework specifically targets students with minimal prior

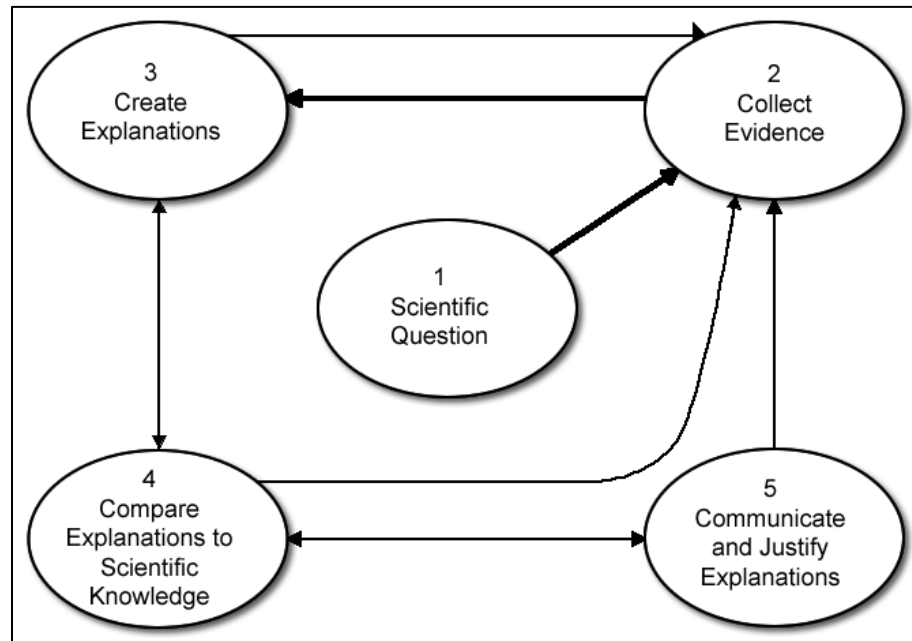
inquiry and self-regulation experiences to develop the skills and abilities that are a crucial part of building the expertise that they lack (Kern *et al.*, in press). Table 1 shows the alignment of 5-DIE with the essential features of inquiry (Kern *et al.*, in press). Each 5-DIE feature aligns with the essential features of inquiry to guide a learner through and to promote reflection on the inquiry process.

Feature 1 of each 5-DIE lesson is focused on a scientific question (i.e., Big Question) that lends itself to empirical investigation. Feature 2 is an evidence collection activity in which learners engage in systematic observations to collect evidence to address the Big Question. In Feature 3, learners analyze evidence and use it to generate a claim statement (e.g., evidence, claim, relationship) related to the science concepts inherent in the Big Question. For Feature 4, learners are given the opportunity to compare their personal claims with the accepted scientific understanding for the content of the lesson. Finally, Feature 5 involves learners communicating their personal claim statements with peers and the teacher and engaging them in a collaborative discussion about the science content. Like the scientific inquiry process itself, 5-DIE (Figure 1) is non-linear and allows learners to progress through and revisit features to meet their learning needs.

Table 1

*Feature Alignment for 5-DIE Design Framework & Inquiry (Kern et al., in press).*

Essential Features of Inquiry (NRC, 2000)	Enactment in the Features of the 5-DIE Design Framework
1. Learner engages in scientifically oriented questions.	1. A big question frames the lesson.
2. Learner gives priority to evidence in responding to questions	2. Learner engages in scaffolded evidence collection tasks through systematic observations or experimentation.
3. Learner formulate explanations from evidence	3. Learner develops a scientific claim statement that includes evidence, claim, and a description of the relationship between the evidence and claim.
4. Learner connects explanations to scientific knowledge	4. Learners engage in the evaluation and revision of their scientific claim statement in light of scientific understanding.
5. Learner communicates and justifies explanations	5. Learner participates in collaborative argumentation by synchronously or asynchronously presenting scientific knowledge claims for peer review.



*Figure 1.* Process diagram illustrating 5-DIE. The partially sequenced structure of 5-DIE is diagrammed with a numerical label on each feature indicating the order the features are completed. The arrows indicate the possible progression through the lesson as well as the recursive nature of 5-DIE (Kern et al., in press).

The numerical label on each feature in the diagram indicates the order of its completion. The arrows among the features indicate the path(s) the learner may follow while working through a 5-DIE lesson. Features-1 through 3 are to be completed first, in sequence without looking ahead to features-4 or 5. Once feature 2 has been completed, the learner may return to it at any point to collect additional evidence to support explanations. All student work is captured and recorded in a Research Brief, modeled after a scientific notebook or white paper, which is submitted to the teacher.

The degree or level of inquiry depends on who is responsible for directing the activity, the teacher or the learner. When compared to open inquiry, where learner progression is unstructured and the learner takes responsibility for all major aspects of the investigation (Anastopoulou, Sharples, Ainsworth, Crook, O'Malley, & Wright, 2012), or a simplified progression, where inquiry is represented as a cycle (Bruce & Bishop, 2002; Llewellyn, 2002; White & Frederiksen, 1998), 5-DIE is designed to guide learners through the inquiry process while promoting autonomous negotiation of the activity and reflection on the process (Kern *et al.*, in press).

5-DIE was developed to promote critical thinking and problem solving, and to make learning science in an inquiry-based cyberlearning environment accessible to all students through meaningful scaffolding. In this research study, the effect of pairing scientific inscription with self-explanation prompts targets both the second essential feature of inquiry, “learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions,” (NRC, 2000, p. 25) and the second feature of 5-DIE. Furthermore, the effect of faded worked examples associated with collaborative argumentation as a targeted learning strategy in the third

essential feature of inquiry, “learners formulate explanations from evidence to address scientifically oriented questions” (NRC, 2000, p. 25), and the third feature of 5-DIE was evaluated as well.

**Scientific practices.** From the inception of 5-DIE, the goal has been to develop in students the skills and abilities associated with the authentic scientific practices embodied in scientific inquiry. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2011) (Framework) identified eight behaviors or practices scientists engaged in while investigating and explaining the natural world. The intent of the scientific and engineering practices is to engaging students in these practices is to allow them to model the activities practiced by scientists in science learning environments (NRC, 2011).

The eight practices are:

- 1) Asking questions and defining problems;
- 2) Developing and using models;
- 3) Planning and carrying out investigations;
- 4) Analyzing and interpreting data;
- 5) Using mathematics, information and computer technology, and computational thinking;
- 6) Constructing explanations and designing solutions;
- 7) Engaging in argument from evidence; and
- 8) Obtaining, evaluating and communicating information. (NRC, 2011, p. 42)

A goal of the 5-DIE design framework is to provide a theory-based, scaffolded learning environment in which learners develop scientific habits of mind, as set forth by eight practices of science and engineering outlined by the Framework (NRC, 2011).

**Scientific inscriptions.** Scientific inscriptions are graphical or pictorial representations of scientific ideas and can include graphs, data tables, and diagrams (Bowen & Roth, 2002). Kindfield and Singer-Gabella (2010) further describe scientific inscriptions as “non-prose externalizations of scientific models, concepts, and phenomena ranging from near literal depictions such as photographs to data displays to mathematical equations” (p. 59). In this study, scientific inscriptions, or representations inscribed or produced as media, are differentiated from representations that are characterized as internal or mental models (Kindfield & Singer-Gabella, 2010; Pozzer-Ardenghi & Roth, 2010; Roth & McGinn, 1998). Scientific inscriptions are central to both understanding and doing science, “yet they are afforded little status in traditional science education practice and research” (Kindfield & Singer-Gabella, 2010, p. 60). Scaife and Rogers (1996) suggest this problem may be due to the assumption of science educators that an expert representation automatically helps a novice learner; therefore, those science educators do not typically explicitly describe the science content represented in an inscription, nor do they point out the strengths and limitations of the inscription.

Scientific inscriptions are integral to creating and communicating scientific understanding and are central to the practices of science. Engaging in scientific practices requires the skills and abilities to produce, interpret, critique, and invent new inscriptions (diSessa, 2004; Wu & Krajcik, 2006). The American Association for the Advancement

Science (1994) (AAAS) recommends engaging learners in practices of science associated with interpreting and reasoning with scientific inscriptions (Wu & Krajcik, 2006).

The 5-DIE design framework uses a variety of representations throughout all features. Scientific inscriptions are used to make scientific concepts explicit, to simulate evidence collection situations, and to represent understanding in the form of a graph, data table, physical, virtual, or mathematical model. Design decisions related to scaffolding the experience learners have with these scientific inscriptions are based on research related to the difficulties learners have interpreting scientific inscriptions.

Learners at all levels of education struggle to interpret scientific inscriptions, yet the presentation of K – 20 science content is conveyed through scientific inscriptions in textbooks, journals, and classroom instruction, as if the interpretation of an inscription is obvious and unproblematic (Bowen & Roth, 1998; Bowen & Roth, 2002; Kindfield & Singer-Gabella, 2010; Pozzer-Ardenghi & Roth, 2010). Atkinson and Renkl (2007) indicate that when learners are provided with scientific inscriptions, most learners study or process them in a passive or superficial way. In their study of why learners struggle with interpreting scientific inscriptions, Bowen and Roth's (2002) evaluated textbooks from high school and college as well as professional scientific journals and found the texts each averaged more than one scientific inscription per page. Interestingly, Bowen and Roth (2002) found regardless of the level of scientific understanding (i.e., primary school through college undergraduate), individuals have difficulties interpreting inscriptions. Bowen and Roth (2002) also found that exposing learners to more complex inscriptions or telling learners when and how to use and interpret inscriptions does not lead to a learner's competency using and interpreting inscriptions. Learners' abilities to



learn from inscriptions were related to the learners' prior knowledge associated with the concepts represented in the inscription.

Kindfield and Singer-Gabella (2010) reported similar results with K–6 pre-service teachers enrolled in an entry-level science course. Rarely were the pre-service teachers prompted to evaluate their own understanding of the inscriptions. The study suggested that learners should be provided with opportunities to reason about and practice interpreting scientific inscriptions, to create ways of representing data, and to critically evaluate the strengths and weaknesses of different scientific inscriptions. From the perspective of learners helping each other learn, Pozzer-Ardenghi and Roth (2010) suggest that socially negotiating the meaning of a scientific inscription results in the learners experiencing multiple avenues to interpret inscriptions while developing the skills and abilities associated with inscriptional practices.

Orgill and Crippen's (2010) study evaluated the incongruence between how an instructor intended students to use a scientific inscription and how the students actually used a scientific inscription. This research provided two key design considerations related to overcoming learner difficulties with scientific inscriptions: learners require prior knowledge to identify specific characteristics necessary to interpret an inscription's meaning and scientific inscriptions have domain specific conventions in which instruction must be made explicit in order for the learner to interpret the inscriptions.

Past and current research recognizes a need for research associated with scientific inscriptions to inform both theory and practice. Inscriptions are ubiquitous in our society and there is a need to address literacy associated with allowing learners to produce, interpret, and critique inscriptions (Roth, 2002). 5-DIE's grounding in the essential

features of inquiry (NRC, 2000) depends on the use, evaluation, and creation of scientific inscriptions in the collection, evaluation, and representation of evidence. Based on the research associated with learners' difficulties with using and interpreting scientific inscriptions, the design decision was made to scaffold learner engagement with scientific inscriptions by pairing them with self-explanation prompts (discussed in detail in the Learning strategy #2: Self-explanation prompts section).

**Scientific argumentation.** Kuhn (1962) emphasized the engagement of scientists in argumentation as a form of quality control as well as a construct for shifting scientific paradigms and the development of scientific ideas. Science, by nature, is socially situated (Rutherford & Ahlgren, 1990) which means the acceptance of any scientific claim by the scientific community is the result of scrutiny and challenges to all aspects contributing to the construction of the claim. Argumentation, therefore, is both a social and collaborative process, necessary for the advancement of scientific understanding (Duschl & Osborne, 2002). The National Research Council (2011, 2000, 1996) emphasizes the role of inquiry and scientific practices, including argumentation, in a science classroom for developing science literate individuals in both the content and the process associated with science. Duschl and Osborne (2002) argue that the process of scientific inquiry without the opportunity to engage in argumentation neglects the very nature of science.

The nature of collaborative argumentation is embodied in the 5-DIE design framework. The inclusion of the learner developed scientific knowledge claim and participation in collaborative argumentation allows the learner's understanding to be reviewed and critiqued of both their peers and teacher. Design decisions associated with facilitating scientific discourse within 5-DIE are based on the confound that learners

engaging in scientific discourse tend to not learn the science content associated with the discourse (Cross, Taasobshirazi, Hendricks, & Hickey, 2008; von Aufschnaiter, Erduran, Osborne, & Simon, 2008).

Within the field of science education, researchers have recognized the important role scientific discourse has in learning science, where scientific discourse engages learners in using scientific theory, data, and evidence to generate and support ideas or claims (Driver, Newton, & Osborne, 2000; Mortimer & Scott, 2003; Newton, Driver, & Osborne, 1999; Nussbaum & Sinatra, 2003). The focus is on engaging students in scientific argumentation, where learners propose, support, criticize, evaluate, and refine their ideas about a scientific topic (Erduran, Simon, & Osborne 2004; Duschl & Osborne, 2002; Newton, Driver, & Osborne, 1999; Nussbaum & Sinatra, 2003; Simon, Erduran, & Osborne 2002). Many of these researchers have worked under the assumption that there is a relationship between learner engagement in argumentation and their conceptual understanding of science concepts, yet the research has focused on finding more effective strategies for enhancing the quality of learners arguments with little regard to the effect argumentation may have on learners science content knowledge. Because the current study is focused on using argumentation to support students' science content learning, the following review will describe research studies that attempt to relate argumentation to conceptual understanding.

Zohar and Nemet (2002) investigated the effects of teaching argumentation skills in the socio-scientific issue of human genetics on students' biological knowledge and reasoning. It was found that learners engaged in the argumentation intervention scored significantly higher on the biological content measure and outperformed the comparison

group on the correct use of biological content when constructing an argument (Zohar & Nemet, 2002). Zohar and Nemet (2002) claimed that argumentation teaches higher-order thinking skills resulting in the acquisition of content knowledge, which is both resilient and transferrable. However, because the study focused primarily on the development of argumentation skills, learner content knowledge prior to the implementation of the curriculum was not surveyed. Consequently, this study indicates the relationship between argumentation and an increase in content knowledge remains uncertain.

Cross *et al.*, (2008) explored the relationship between learning gains on biology content and engagement in scientific argumentation. The design included two measures: one measure that assessed science content directly related to the arguments learners constructed (proximal transfer) and a second standards-based measure (distal transfer). There were modest gains in the proximal transfer measure and no significant gain on the distal transfer measure. Cross and colleagues suggested that learning both argumentation and content simultaneously might have been overwhelming, preventing the learning of the science content. Ruiz-Primo, Shavelson, Hamilton, and Klein (2002) found similar results where learning gains were achieved on an assessment that was directly related to the content but not on a generalized measure.

von Aufschnaiter *et al.*'s (2008) study took a critical look at how argumentation influences learners' prior knowledge and integration of new science content. Interestingly, von Aufschnaiter and her colleagues found that when learners are engaged in learning how to argue, they draw on prior knowledge to develop their argument rather than incorporating the new content learned during the instructional unit. They also found that when a learner had no prior knowledge of the content associated with the argument,

there was limited or no engagement in argumentation. The results of this study are significant considering the large body of research related to the effect of prior knowledge on learning. The results also have implications on designing instruction to promote argumentation. Use of argumentation, as a learning strategy to contrast scientific understanding with learners' everyday concepts, will only result in meaningful discourse of the scientific concepts when learners already have some experience with, or understanding of, the scientific topic. Norris and Phillips (2003) argued, it is not possible for learners to participate in the meaningful learning of a scientific concept unless they have some scientific literacy related to the topic. Consequently, engaging learners in scientific argumentation based on scientific concepts if they lack prior knowledge of or prior experience with is inappropriate (von Aufschnaiter *et al.*, 2008).

Cross *et al.*, (2008) recognized that the modest gains in content knowledge may be a result of the learner being overwhelmed with learning how to argue and learning content at the same time. However, the opportunity for the learner to engage in their prior conceptions (von Aufschnaiter *et al.*, 2008) may have led the learner to correct misconceptions through argumentation, resulting in gains in content knowledge. The learner is addressing prior conceptions and potentially correcting them while engaging in argumentation. There may be a conflict between the learners' prior knowledge and the new content, meaning the intrinsic nature of the prior knowledge is used when developing an argument and the new content is extraneous therefore it does not become a part of the long-term memory.

Scientific discourse is a central construct in science, yet research in science education indicates that learners who engage in argumentation do not necessarily learn

the content associated with the argument. 5-DIE's grounding in the essential features of inquiry (NRC, 2000) depend on learners engaging learners in the development of a meaning representation of their scientific understanding in the form of a claim statement followed by the negotiation of their ideas as they participate in collaborative argumentation. The design decision to scaffold the evaluation and development of a scientific claim statement with faded worked examples in the current study is based on the need to address the research finding that learners who engage in scientific discourse tend to not learn the science content associated with the discourse.

**Cyberlearning.** The 5-DIE design framework uses network computing and communications to personalize the science learning experience of all students regardless of prior experience in science, self-efficacy, or level of self-regulation by providing systematic guidelines for the development of an authentic science lesson framed by a scientific question related to the interests of the learners. Through the research and development of 5-DIE I seek to contribute to the body of literature related to how technologies that afford immediate access to original data, use online analytical and visualization tools, and offer participation in public discourse related to scientific questions can be integrated into cyberlearning environments as engaging and authentic scientific practices (Martinez & Peters Burton, 2011).

### **Cognitive Load Theory: Guiding Theory of Learning Strategies**

Cognitive load theory (CLT) has emerged over the past twenty years as an influential theory for learning and instructional design. The primary claim of this theory is that without considering a learner's cognitive architecture, the effectiveness of instructional design is likely to be random (Schnotz & Kurschner, 2007). By taking into

consideration the capabilities and limitations of the learner's cognitive architecture, design decisions can be made to influence learning. CLT explains the relationship that exists between working memory and learning, or the development of a schema in long-term memory.

In terms of a learner's ability to store and process information, CLT assumes that working memory is limited to approximately seven chunks of information (Sweller, 1988). The restricted nature of working memory is restricted further when processing new or complex information (van Gog, Paas, & van Merriënboer, 2008). Theoretically, long-term memory can store an unlimited amount of organized knowledge or schema (Kalyuga *et al.*, 2003). The goal of learning strategies is to help the learner develop specific schema in long-term memory that are organized, categorized, and automated for a problem solution (Kalyuga *et al.*, 2003).

Cognitive load refers to any demand on working memory storage and processing of information (Schnotz & Kirschner, 2007). There are three types of cognitive load experienced by learners: 1) intrinsic, 2) extraneous, and 3) germane. Intrinsic cognitive load refers to the interplay that occurs between long-term and working memory or the influence prior knowledge has on working memory—the greater the prior knowledge the lower the intrinsic cognitive load. Cognitive load is also affected by external factors such as the influence of instructional design on working memory. Extraneous cognitive load refers to the demand instructional design places on working memory with processing that is unrelated to schema development or the organization of knowledge about a specific concept (Merriënboer, Kirschner, & Kester, 2003) resulting in ineffective or non-learning. Germane cognitive load occurs when instructional design engages learners in

processing that leads to the development of a cognitive schema or influences the storing of information in long-term memory (Kalyuga *et al.*, 2003; Sweller, 1988). Germane and intrinsic cognitive load are more desirable than extraneous load.

Cognitive load theory helps us understand why presenting novices with new concepts and procedures for problem solving results in extraneous cognitive load and, therefore, little learning because the abundance of new information taxes the working memory. Carefully designed lessons that support the engagement of a learner by reducing extraneous cognitive load and fostering germane cognitive load result in increased learning, increased learning efficiency, and greater depth of learner's understanding (Crippen & Brooks, 2009). Therefore, selection of an appropriate strategy or technique is an essential component of the lesson design.

Jonassen, Grabinger, and Harris (1991) refer to the individual interventions implemented aimed at obtaining specific learning objective as learning strategies. The two learning strategies used in this study, self-explanation prompts and faded worked examples, are discussed in the next section. Both learning strategies are grounded in CLT and chosen for this study specifically because they are designed to shift the content towards germane cognitive load.

### **Learning Strategies**

The 5-DIE lesson central to this study draws on the bodies of research related to designed affordances that provide the structure and support for a learner to engage in a problem-solving task in a meaningful way, specifically with scaffolds called self-explanation prompts and worked examples. In the following section a more extensive explanation of scaffolding and the research associated with the effect of worked



examples, worked examples paired with self-explanation prompts, and faded worked examples are considered.

**Scaffolding.** Scaffolding is grounded in Vygotsky's (1978) zone of proximal development (ZPD). The ZPD is described as the difference between the actual independent abilities of a learner and potential development of the same learner when assisted by an expert. Scaffolding refers to the instructional support provided to learners that allows them to engage in a task in a productive manner beyond their independent abilities (Kim & Hannafin, 2004). Sharma and Hannafin (2007) state that the ZPD is "a conceptual framework for selecting individual learning tasks, while scaffolding provides a strategic framework for selecting and implementing strategies to support specific learning" (p. 28). From a CLT perspective, learning strategies that are scaffolds are meant to shift extraneous cognitive load toward germane cognitive load, enabling a learner to complete a task that would otherwise be outside their independent abilities (Snchotz & Kurschner, 2007). In the context of the current study, scaffolding is the specific affordance of the instructional design that provides cognitive and social supports developed to strengthen learner content knowledge acquisition (Kim & Hannafin, 2004).

Kim and Hannafin (2004) categorize types of scaffolds into procedural, conceptual, metacognitive, and strategic. Procedural scaffolds are meant to reduce the extraneous cognitive load associated with negotiating the learning environment and routine procedure. Conceptual scaffolds help learners bridge the gaps between what they already know and what they need to know. Metacognitive scaffolds support the learner in assessing personal understanding, reflecting on their thinking, and monitoring their

learning progress. Strategic scaffolds help students to consider alternative approaches to addressing problems.

Although the 5-DIE design framework includes each scaffold type, this study has focus on conceptual scaffolds. The degree to which the learner was scaffolded varies according to the demands posed on the learner within the learning environment. The fading or removal of scaffolds was dependent upon the needs of the learners; and when the needs of the learner cannot be definitively determined in advance, scaffolding remains in place continuously (Kim & Hannafin, 2004). As the needs of the learner can be determined and when the learner develops specific skills related to content, self-regulation, reflection, and/or collaboration, the scaffolds are removed as the learner's skills develop. In this study there was a diverse population of learners participating in the lessons; therefore, all of the scaffolds remain in place throughout the lesson design with the exception of the faded worked examples learning strategy.

In the sections below, a description and illustration of the effect or advantage of worked examples as a learning strategy in relationship to cognitive load theory is presented, as well as descriptions of multiple research studies consistent with a wide body of relevant research on the effect of worked examples. This is followed by a discussion of explaining self-explanation prompts as a learning strategy and the research related to the effect self-explanation prompts have on the acquisition and retention of content knowledge.

**Learning strategy #1: Faded worked examples.** Jonassen (1997) identifies a well-structured problem as having a definite initial state where the problem to be solved is identified and all components of the problem are provided to the learner, a known goal

state or the nature of the solution is well defined, and a known procedure for solving the problem. Worked examples provide detailed problem solutions with the processes used to solve a problem made explicit to the learner (Crippen & Earl, 2007). Worked examples usually have three parts: a problem state, a goal state, and a structured solution (Crippen & Earl, 2007). The provided solution gives some structure for understanding how the problem is solved without a script or procedure for the solution, rather the opportunity to engage self-explanation to understanding the structure of the solution.

The effectiveness of studying worked examples for learning may be explained by CLT (Sweller 2005; Sweller, van Merriënboer, & Paas, 1998). Instructional design incorporating worked examples reduces extraneous cognitive load, resulting in productive and efficient learning (Clark, Kirschner, & Sweller, 2012; van Gog & Rummel, 2010). This is referred to as the worked example effect; worked examples reduce the cognitive load imposed on working memory by minimizing extraneous cognitive demands, allowing the learner to focus on understanding the application of the principles in the presented solutions (Rourke & Sweller, 2009; Renkl *et al.*, 2004; Sweller & Cooper, 1985; van Gog *et al.*, 2008). Extensive research has been conducted on the use of worked examples with well-structured problem solving tasks (e.g., Cooper & Sweller, 1987; Sweller & Cooper, 1985; Van Gog *et al.*, 2006; Kissane, Kalyuga, Chandler, & Sweller, 2008) and more recently on the implementation of worked examples in collaborative learning environments (Rummel, Spada, & Hauser, 2009).

Over the past 25 years, research has shown that worked examples are a robust and meaningful learning strategy (Retnowate, Ayres, & Sweller, 2010). Cognitive load theory explains why the worked example effect works (Crippen & Earl, 2007; Kalyuga, Ayres,

Chandler, & Sweller, 2003; Renkl, Atkinson, & Grobe, 2004; Sweller & Cooper, 1985; van Gog, Paas, & van Merriënboer, 2008). Worked examples, as with many learning strategies, provide the explicit instruction necessary for the novice learner to effectively and efficiently learn (Clark, Kirschner, & Sweller, 2012; Sweller & Cooper, 1985; van Gog *et al.*, 2008). Yet, as the novice learner's expertise increases, there is the potential for the explicit instruction associated with the worked example to become extraneous cognitive load, negatively effecting learning (Clark *et al.*, 2012; Kirschner *et al.*, 2006; Renkl *et al.*, 2004). This effect is referred to as the expertise-reversal effect.

**Expertise reversal effect.** The effectiveness of instructional design is related to the influence prior knowledge has on cognitive load or intrinsic cognitive load.

Implementing worked examples with learners with low prior knowledge of problem solutions was found to be effective; yet using worked examples with individuals with high prior knowledge was less effective or ineffective (Clark *et al.*, 2012; Kalyuga *et al.*, 2003). Redundant information taxes the working memory, leading to less than optimal learning conditions for learners with high prior knowledge. The inclusion of information that is redundant for the high prior knowledge learner reduces engagement in active learning (Crippen & Brooks, 2009). This is referred to as the expertise-reversal effect.

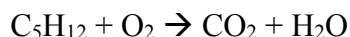
The expertise reversal effect occurs when added information increases extraneous cognitive load because the learner already has an existing schema for solving the problem and working memory is required to process the redundant information (Clark *et al.*, 2012; Kalyuga *et al.*, 2003). The implication for the implementation of worked examples is the reduction of extraneous cognitive load for learners with low prior knowledge but an

increase in extraneous cognitive load of learners with high prior knowledge (Kalyuga *et al.*, 2003).

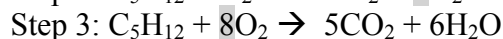
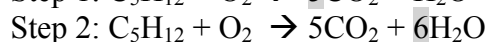
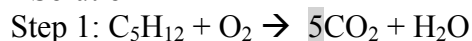
Studies have also confirmed this hypothesis. van Gog *et al.*, (2008), for example, investigated the impact of sequencing product-oriented and process-oriented worked examples. Typically, worked examples are product-oriented (Figure 2), meaning the focus is on the final solution rather than understanding the process associated with the solution. van Gog *et al.* (2008) identified this as problematic because knowing the procedures for solving a problem “is not enough to understand it, and understanding is necessary for transfer” (pg. 213).

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Balance the following chemical reaction.



Problem Solution



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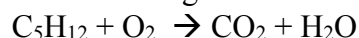
*Figure 2.* Product-oriented worked example. This figure illustrates the structure of a product-oriented worked example. (modified from [http://www.skyweb.net/science/balancing\\_chemical\\_equations\\_examples.html](http://www.skyweb.net/science/balancing_chemical_equations_examples.html))

Another type of worked example is the process-oriented worked examples (see Figure 3). Process-oriented worked examples may include information about the principles and strategies associated with the solution procedures or they may be accompanied by self-explanation prompts or prompts that encourage personal dialogue or

self-talk while problem solving. The goal of process-oriented worked examples is to shift identifying the purpose of steps in the solution procedures to towards germane cognitive load.

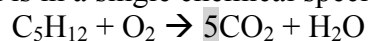
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Balance the following chemical reaction.

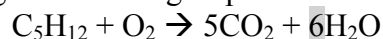


Problem Solution

Step 1: There are five carbons on the left but only one on the right, and on each side the carbon is in a single chemical species. Put a 5 in front of the CO<sub>2</sub> on the right side.



Step 2: There are twelve hydrogen atoms on the left but only two on the right side, and hydrogen is in a single species on each side. Put a 6 in front of the H<sub>2</sub>O on the right side.



Step 3: Finally, there are only two oxygen atoms on the left but 16 of them on the right side. So put an 8 in front of the O<sub>2</sub> on the left side.



It's now a balanced chemical equation.

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*Figure 3. Process-oriented worked example. This figure illustrates the structure of a process-oriented worked example. (modified from [http://www.skyweb.net/science/balancing\\_chemical\\_equations\\_examples.htm](http://www.skyweb.net/science/balancing_chemical_equations_examples.htm))*

van Gog *et al.*, (2008) found that sequencing process-oriented worked examples prior to product-oriented worked examples initially fostered learning ( $\eta^2 = .46$ ). When learners were subjected to additional process-oriented worked examples, however, learning was hampered because the expertise-reversal effect became an issue and the redundant information contributed to extraneous cognitive load. They also found that learners were able to fill in the gaps if they were presented with product-oriented worked

examples first and then process-oriented worked examples. It appears that enough information pertaining to the problem-solving schema can be learned to bridge gaps with subsequent exposure to process or product-oriented worked examples.

In another study Retnowati *et al.* (2010) evaluated the effect of worked examples implemented in both group and individual settings for similar as well as novel problem sets. The implementation in each setting was devoid of teacher support or encouragement of collaborative discourse. The results of Retnowati *et al.*'s (2010) study showed learners who engaged in worked examples, when presented with problems similar to the worked examples and practice problems, were more accurate in the procedures and reasoning both in individual and group settings than learners engaging in problem solving ( $\eta^2 = 0.29$ ). When learners were presented with a transfer test designed to measure their ability to apply material learned to more complex problems, learners using worked examples, both individual and group, significantly improved in reasoning scores ( $\eta^2 = 0.18$ ).

Retnowati *et al.* (2010) expected the participants who engaged with worked examples in a group setting to have the greatest influence on learning. The anticipation of the group setting having the greatest influence on reasoning scores was related to the expected discourse associated with the problem solving process. Even though they found improvement it was not significantly higher than the individual setting. The authors provided two possible explanations for this outcome: 1) the low degree of collaboration within the group setting and 2) the potential for extraneous cognitive load in the form of redundant information (expertise-reversal effect) associated with any collaborative discourse.

Kirschner *et al.*, (2006) identified the use of worked examples as an exemplar of guided instruction; yet van Gog *et al.* (2008) and Retnowati *et al.*'s (2010) studies both exemplify the relationship that exists between the effective use of worked examples and the potential for worked examples to be a detriment to learning. These studies are examples of the traditional method of implementing worked examples where there is a drastic change in demands as a learner transitions from a completely worked example to problem solving independently. For example, the learners are presented with a worked example to evaluate prior to solving a problem on their own. Faded worked examples may be an element of instructional design used to shift towards germane cognitive load by systematically removing steps to the worked example lessening the drastic change in cognitive demands on a learner.

**Faded worked examples.** In an attempt to provide a structured transition from completely worked examples to independent problem solving, the cognitive demands of problem solving are introduced through the process of removing solution steps in the worked examples and having the learner provide missing solution steps until the learner can provide all solution steps (Crippen & Brooks, 2009).

Renkl *et al.* (2004) found that the use of faded worked examples resulted in more efficient learning as well as acquisition of the problem-solving schema. In their study, the environment was under controlled conditions in a computer lab where undergraduate educational psychology students were randomly assigned a computer with either the control or treatment condition. The control group was provided with example-problem pairs. An example-problem pair is described as the participants being provided with an example of how to solve a problem with no further explanation or instruction about



solving the problem (product-oriented). The participants were then asked to solve a similar problem. The treatment group was provided a faded worked example where the problem solution was presented in its entirety and the problem to be solved had one step removed from the problem solution requiring the participant to only complete the missing step. The time spent solving the problems, time on specific task, and a Think Aloud protocol was recorded.

The control group experienced a greater number of impasses where long periods of time were taken to work through parts of the problem. The treatment group experienced a smoother transition or fewer impasses while solving the problem. Furthermore, the near transfer effect size was described as medium to high ( $\eta^2 = 0.09$ ) and far transfer was described as strong effect size ( $\eta^2 = 0.13$ ) indicating faded worked examples resulted in more efficient learning as well as acquisition of the problem-solving schema. Renkl *et al.* (2004) determined faded worked examples not only reduced redundant information but also, through unprompted self-explanations, facilitated germane cognitive load resulting in learning. Maximum guidance is provided to learners through faded worked examples (Renkl *et al.*, 2004). As a learner's problem solving skills expertise increases, the solution steps are gradually reduced or faded. The gradual fading of the solution steps result in the metacognitive processes in self-explanation.

In a similar study Kissane, Kalyuga, Chandler, and Sweller (2008) under controlled conditions randomly assigned financial services employees to a problem-solving group, a example-problem control group, or a faded worked example group. The problem solving participants were provided with four problems to solve and were given five minutes for each problem. The example-problem pair participants were presented

with the example problem solution to study for five minutes followed by three similar problems to solve without scaffolding and were given five minutes for each problem. The faded worked example participants were provided with the four problems successively faded. Participants were given five minutes to complete each problem. Kissane *et al.* (2008) found no significant difference in posttest scores. On a delayed posttest however, significant differences were found with a strong effect size ( $\eta^2 = 0.15$ ) for the faded worked example group when compared to the problem-solving group.

Renkl *et al.*'s (2004) study also evaluated two types of faded worked examples: the gradual elimination of steps from the last step to the first (backward fading) or the gradual elimination of steps from the first step to the last (forward fading). Comparing the two fading conditions resulted in no differences with respect to learning or errors during learning on either transfer post-tests or delayed transfer post-tests. They found that participants exposed to the backward fading technique required less time to learn the problem solution. Fading may have resulted in learners acquiring specific knowledge about the faded solution step because the structured impasses (i.e., faded step) may have led to self-explanation. With respect to cognitive load theory, the initial implementation of worked examples reduces the extraneous cognitive load with prior research suggesting that providing additional worked examples with redundant information may lead to the expertise-reversal effect. Faded worked examples not only reduced redundant information but also through unprompted self-explanations facilitated germane cognitive load resulting in learning (Renkl *et al.*, 2004).

Schwonke, Renkl, Krieg, Wittwer, Aleven, & Salden, (2009) challenge the notion that faded worked examples are a meaningful learning strategy only when compared to

“lousy control conditions” (p. 258) but not when compared to well-supported problem-solving. In two experiments, Schwonke *et al.* (2009) compared a computer-based cognitive tutor, which provides individualized support for scaffolded learning by selecting appropriate problems for the participants to solve, giving just-in-time feedback and presenting hints, to an enhanced version of the cognitive tutor containing faded worked examples. In the first experiment, participants in the faded worked example condition required less learning time to gain a similar amount of procedural skills and conceptual understanding than participants in a control group ( $\eta^2 = .07$ ). The efficiency advantage was replicated in the second experiment though no significant differences in terms of learning outcomes were found. Schwonke *et al.* (2009) claim the results of their study demonstrate the “worked-example effect is indeed robust and can be found even when compared to well-supported learning by problem-solving” (p. 258).

Table 2 identifies the control condition, experimental condition, and the effect size of the three worked example studies described. In general, when worked examples are compared to problem-solving where little or no scaffolding is provided the effect size is large. When faded worked examples are added to an environment rich in scaffolding, participants required less time to learn the problem-solving skills yet there was no significant difference learning outcomes.

Table 2

*Overview of Research Conditions & Results for Faded Worked Examples.*

<b>Citation</b>	<b>Control Conditions</b>	<b>Treatment Condition</b>	<b>Results</b>
Renkl, Atkinson, & Grobe, (2004)	Example-Problem Pair	Faded Worked Example	Large effect size ( $\eta^2 = 0.18$ ).
Kissane, Kalyuga, Chandler, & Sweller, (2008)	Problem Solving Example-Problem Pair	Faded Worked Example	Large effect size ( $\eta^2 = 0.15$ ).
Schwonke, Renkl, Krieg, Wittwer, Aleven, & Salden, (2009)	Cognitive Tutor	Faded Worked Examples	Learning efficiency: Medium effect size ( $\eta^2 = .07$ ) Learning outcomes: negligible effect size ( $\eta^2 = .002$ )

*Note.*  $\eta^2$  = partial eta squared; small effect size .01; medium effect size .06; large effect size = .15 (Keppel & Wickens, 2004)

Faded worked examples provide a conceptual scaffold in which a structured transition from completely worked examples to independent problem solving is displayed. Research indicates faded worked examples are an efficient learning strategy that results in the development of problem solving skills. Researchers attribute the shift in cognitive load from extraneous to germane to the gains in problem-solving skills as well as the structured impasses created when a step is faded resulting in self-explanation. Therefore it is hypothesized that using faded worked examples to scaffold the evaluation and development of a scientific knowledge claim during a 5-DIE lesson will result in the acquisition and retention of domain-specific content knowledge.

**Learning strategy #2: Self-explanation prompts.** Self-explanation involves a personal dialogue or self-talk while problem solving (Crippen & Earl, 2007) or evaluating a worked example. Self-explanation prompts are conceptual scaffolds designed to guide students through the self-explanation process as they work to understand and integrate the concept, procedure, or representation (Berthold, Eysink, & Renkl, 2009; Gerjets, Scheiter, & Catrambone, 2006) in a worked example. The success of worked examples is dependent upon the prior knowledge of a learner as well as the learner's engagement in understanding the problem solution. The guidance provided by self-explanation prompts reduce the extraneous cognitive load associated with unguided activities, therefore providing a direction for the cognitive processing necessary for learning (Kirschner *et al.*, 2006). Prompting cues learners in the identification of processes and purposes for each step used to solve problems in route to understanding the solution.

The following are examples of Self-Explanation prompts (Crippen, Archambault, & Kern, in press):

- When I look at the two representations of photosynthesis I see the following similarities...
- The similarities in the two representations are important because...
- The reason I calculated \_\_\_\_\_ first is...
- When I look at the food web, the arrow between organisms represents...
- Worked example where student explains the steps to solving a complex or well-structured problem.

Self-explanation prompts coupled with some level of instructional assistance like worked examples provide learners with the guidance needed to avoid time off-task or failure. The guidance provided by prompting reduces the cognitive load associated with unguided activities, therefore shifting the cognitive processing to germane cognitive load necessary for learning (Kirschner *et al.*, 2006).

Crippen and Earl (2007) evaluated the effect of Web-based worked examples combined with self-explanation prompts on learning and self-efficacy. The experimental design included first year undergraduate chemistry students randomly assigned to one of three groups: a group provided with worked examples, a group provided with both worked examples and self-explanation prompts, and a control group in which neither worked examples nor self-explanation prompts were provided. When worked examples were paired with self-explanation prompts the results indicated an improvement in performance on assessment ( $\eta^2 = 0.08$ ) though there was not a statistical significant difference which was attributed to a small sample size. The results in this study were inconclusive when learners engaging in worked examples without a prompt to identify and explain the purpose of steps in the problem solution. The implications of the no significant difference results of this study are that worked examples, on their own, may not be enough to help learners because spontaneous self-explanation that may occur when presented with a worked example may be superficial or completed in a passive rather than active way (Renkl, Hilbert, & Schworm, 2009; Schworm & Renkl, 2007).

Berthold *et al.* (2009) recognized the high level of germane cognitive load associated with self-explanation prompts. Berthold *et al.*, (2009) compared prompts in which the learner was required to fill in a blank, called assisting self-explanation prompts;

open question designed to induce self-explanation, or open self-explanation prompts; or provided no prompting for self-reflection. The participants were undergraduates in an experimental setting consisting of one 2-hour session. When the self-explanation prompt group was compared to the no prompts group, a significant difference was found ( $\eta^2 = 0.89$ ); yet when comparing the assisting and open self-explanation prompts, no significant difference was found. Berthold *et al.* (2009) found that self-explanation required the learner to process content and resulted in the learner evaluating and reflecting upon content. However, self-explanation did not occur when students were not prompted. Berthold *et al.* (2009) advocated for prompts that include some level of instructional assistance rather than open prompts. Similar to Kirschner *et al.* (2006), Berthold *et al.* (2009) found that students who are provided with self-explanation prompts that include some level of instructional assistance are less likely to make errors, flounder, or completely fail.

van der Meij and de Jong's (2011) study examined whether learning with a computer-assisted simulation-based learning environment designed to support learners with directive self-explanation prompts led to improved learning results when compared to learning in the same environment in which general self-explanation prompts supported learners. The directive self-explanation prompts guided participants to specifically compare and explain inscriptions while general self-explanation group received stated in a less specific or general way. A significant difference was found in favor of the directive self-explanation prompts on the overall posttest scores, yet the effect size was weak ( $\eta^2 = 0.025$ ). van der Meij and de Jong (2011) concluded that focusing learner

reflection on specific relationships between inscriptions is a “good way to support students in their inquiry process” (p. 420).

Table 3 identifies the control condition, experimental condition, and the effect size of the three self-explanation prompt studies described. In general, when self-explanation prompts are compared to little or no scaffolding the effect size is medium to large. When specific self-explanation prompts are compared to less specific self-explanation prompts a significant difference may exist yet there is a small effect size.

Table 3

*Overview of Research Conditions & Results for Self-Explanation Prompts.*

Citation	Control Conditions	Treatment Condition (s)	Results
Crippen & Earl, 2007	Control (no intervention)	Worked Examples with Self-explanation prompts	Medium effect size ( $\eta^2 = 0.08$ ).
Berthold <i>et al.</i> (2009)	Open Questions	Assistive Self-explanation prompts Open self-explanation prompts	Large effect size ( $\eta^2 = 0.89$ ).
van der Meij & de Jong (2011)	General Self-Explanation prompts	Directive Self-Explanation prompts	Small effect size ( $\eta^2 = 0.025$ )

*Note.*  $\eta^2$  = partial eta squared; small effect size .01; medium effect size .06; large effect size = .15 (Keppel & Wickens, 2004)

Crippen and Brooks (2009) indicated when worked examples are used in passive learning environments they are ineffective. Learning outcomes increase with high levels of scaffolding and within active learning contexts, but as the learner's skills improve, the



scaffolds should be slowly removed or faded. Increasing the guidance with self-explanation prompts and fading the worked examples structures the transition between the use of worked examples in the early stages of skill acquisition to problem solving in the later stages. Therefore it is hypothesized that learning with scientific inscriptions by prompting self-explanation during a 5-DIE lesson results in the acquisition and retention of content knowledge. The scaffolding of scientific inscription with self-explanation prompts (a) shifts cognitive load from extraneous to germane and (b) makes explicit the science concepts represented in the scientific inscription resulting in the emphasis of the science content, resulting in the meaningful acquisition and retention of content knowledge.

### **Implications for Science Education**

The goal of science education is to develop science literate individuals (AAAS 1993; NRC 1996). In the English language, literacy is understood in two distinct but related ways (Norris & Phillips, 2003). One perspective on literacy is in terms of the ability to read and write. Another perspective is the idea of knowledgeability, learning, and education (Norris & Phillips, 2003). According to the second perspective, science literacy requires an individual to do more than describe their understanding of a science concept or apply distinct components of science. Rather, a scientifically literate individual has the ability to accurately and effectively interpret and construct science-based ideas (Cavagnetto, 2010).

John Dewey (1933) argued that science is more than a body of knowledge to be learned; science is a process and a method to learn as well. Science is a way of knowing. The formal reasoning and the formal process of deduction or induction that result in a

scientist's conclusion are thought by philosophers to be the very processes that distinguish science from other ways of knowing the world (Sadler, 2004). Scientific discourse and inscriptions are at the heart of scientific knowledge. Argumentation and inscription are how science knowledge is structured and represented. From the historical discussions of Socrates to the philosophical ideas of Thomas Kuhn, the nature of science is grounded in the construction, representation, and refutation of theories as explanation of how our world may be (Chalmers, 1978). The construction and refutation of scientific knowledge is achieved through scientific discourse and science is explained and represented, in part, by scientific inscriptions.

The implications this study has for science education is understanding the effectiveness of scaffolding learner engagement with scientific inscriptions through prompted self-explanation and scaffolding the evaluation and development of a scientific knowledge claim with faded worked examples in the chaotic and naturalistic setting of a high school science classroom. This contribution is meant to inform science teaching practices related to scientific literacy, self-efficacy, engendering conceptual understanding about that natural world, and conveying ideas about the nature of the scientific enterprise through theory based learning strategies. Furthermore, the implications of this study will directly influence design decisions associated with future innovations and iterations of the 5-DIE design framework, resulting in contributions to research related to how learning technologies can provide a personalized science learning experiences for students regardless of prior experience in science, self-efficacy, or level of self-regulation by providing systematic guidelines for the development of an authentic science lesson.

## **Focus of This Study**

The research and development of 5-DIE was initiated as a response to the demand for an online, inquiry-based, science-learning environment designed to promote critical thinking and problem solving (Kim & Hannafin, 2004). This design-based research is intended to inform the design and development of the inquiry-based 5-DIE design framework for cyberlearning environments and to inform theory associated with the difficulties learners have with scientific inscriptions and the consequences related to using argumentation to learn science content.

This study focuses on understanding the potential differences in content learning depending upon whether learners experience one of the following conditions during a science activity:

- Engaging in a 5-DIE lesson.
- Engaging in a 5-DIE lesson with embedded scientific inscriptions paired with self-explanation prompts.
- Engaging in a 5-DIE lesson with embedded faded worked examples scaffolding the evaluation and development of a scientific knowledge claim.
- Engaging in a 5-DIE lesson containing both scientific inscriptions paired with prompted self-explanation and faded worked examples scaffolding the evaluation and development of a scientific knowledge claim.

Scientific inscriptions are representations of science content. They are a mode for communicating ideas, concepts, theories, and laws in science. Furthermore, these inscriptions are pervasive throughout science education contexts as well as in our

everyday interactions with society (Bowen & Roth, 2002). Newspaper or news reports, for example, frequently include a graph or a diagram to represent a socio-scientific issue like global climate change or fossil fuel consumption. Unfortunately learner engagement with scientific inscriptions is often times cursory, resulting in limited or no understanding associated with science content (Atkinson & Renkl, 2007).

Attempts have also been made to relate learner engagement in scientific argumentation to content knowledge acquisition yet the intervention describes previously placed an emphasis on learning how to argue, not the acquisition and retention of content knowledge. The emphasis for this study was on the acquisition and retention of content knowledge where the engagement in the process of learning with scientific inscriptions and scientific argumentation is viewed as a learning strategy rather than a learning outcome.

The pragmatic aspect of this study implies that it will contribute to the refinement of both theory and practice related to scaffolding engagement with scientific inscriptions and arguments. This study also seeks to inform K-12 science teaching practices in development of the skills and abilities of the scientifically literate citizens who, when presented with an inscription or an argument, can use the critical thinking and problem solving necessary to evaluate and understand the content represented when making personal and societal decisions.

## Chapter 3 Methods

### Overview

This study is situated within a larger effort to inform the design and development of the inquiry-based 5-Featured Dynamic Inquiry Enterprise (5-DIE) design framework for cyberlearning environments (e.g., Kern *et al.*, in press) and to advance current educational theories associated with learners' difficulties understanding and using scientific inscriptions and argumentation to learn science content. Specifically, this study focused on how the following interventions when embedded in a 5-DIE lesson affected the acquisition and retention of scientific content knowledge:

- Prompting self-explanation with scientific inscription.
- Evaluating and developing a scientific knowledge claim scaffolded with faded worked examples.
- Combining the prompting of self-explanation with scientific inscription and evaluating and developing a scientific knowledge claim scaffolded with faded worked examples.

Previous research indicates that teaching with scientific inscriptions and scientific discourse does not necessarily result in the acquisition of science content knowledge (e.g., Bowen & Roth, 1999; Cross *et al.*, 2008; Pozzer-Ardenghi & Roth, 2010; Ruiz-Primo, Shavelson, Hamilton, & Klein, 2002; Zohar & Nemet, 2002). For example, Bowen and Roth (2002) found that teaching with inscriptions or telling learners when and how to use inscriptions as well as how to interpret an inscription did not lead to a learner's competency using and interpreting inscriptions. In another study, Hamilton and Klein (2002) found modest learning gains on an assessment item directly related to the

content but no significant gain on the distal transfer assessment when learners were told when and how to use inscriptions. Yet scientific inscriptions and argumentation are keystone concepts in the very nature of scientific knowledge and are the foundational elements in 5-DIE (Kindfield & Singer-Gabella, 2010). In Feature 2 of 5-DIE, learners collect evidence and represent it with a scientific inscription, such as a data table, graph, or model. When learners engage with these inscriptions (i.e., recording, organizing, and representing information) in a passive or superficial way, their understanding of the content and the inscriptions is limited (Atkinson & Renkl, 2007). Individuals who passively engage with scientific representations do not generate meaningful self-explanations (Atkinson & Renkl, 2007). Therefore, making the representations and science content of the inscription explicit by prompting reflective self-explanation may make the processes and representations of science accessible to the novice learner, which could result in meaningful learning. The guided nature of a 5-DIE lesson transitions the participants from gathering evidence to the development of an explanation that addresses a scientifically oriented question in the form of an argument. Subsequently, scaffolding the process of evaluating and developing the foundation of an argument through faded worked examples (i.e., multiple detailed claim statements presented with components removed with each subsequent statement presented) could result in meaningful learning.

This study explored how scaffolding students' engagement with the scientific inscriptions through explicit, reflective self-explanation prompts designed to emphasize the science content represented in scientific inscriptions effected the meaningful acquisition and retention of content knowledge. This study also examined the affect of scaffolding argumentation with faded worked examples to shift the learner's focus from

learning how to argue to learning the science content, on the acquisition and retention of content knowledge.

In feature 3 of 5-DIE, learners engage in the development of a scientific knowledge claim (i.e. evidence, claim, reason) in preparation for collaborative argumentation. Previous research has shown that gains in content knowledge are hampered when argumentation and science content are taught simultaneously (e.g., Cross *et al.*, 2008). Cross *et al.* (2008) evaluated the relationship between learning gains on biology content and engagement in scientific argumentation. They found modest gains in their assessments of proximal transfer and no significant gain on their assessment of distal transfer. Cross *et al.* (2008) suggested that learning both argumentation and content simultaneously might have prevented learners from acquiring the science content. Moreover, von Aufschnaiter and colleagues (2008) suggested that when learners are new to engaging in argumentation they draw on prior knowledge rather than the intended content. von Aufschnaiter *et al.* (2008) also found that limited prior knowledge prevented learners from engaging in argumentation. The current study proposed that scaffolding argumentation with faded worked examples would shift the emphasis to learning scientific content rather than argumentation.

### **Research Questions and Hypotheses**

- 1) What effect does learning with inscriptions paired with self-explanation prompts during evidence collection in a 5-DIE lesson have on the acquisition and retention of domain-specific content knowledge?

- 2) What effect does faded worked examples for the evaluation and development of scientific knowledge claims during a 5-DIE lesson have on the acquisition and retention of domain-specific content knowledge?
- 3) Is there an effect related to inscriptions paired with self-explanation prompts and use of faded worked examples for the scientific knowledge claims on the acquisition and retention of domain-specific content knowledge?
- 4) How can the results of this study contribute to the further innovation of 5-DIE?

**Research hypothesis related to the self-explanation condition.** Learning from scientific inscriptions by prompting self-explanation during a 5-DIE lesson is hypothesized to support the acquisition and retention of content knowledge. The scaffolded scientific inscription with self-explanation prompts (a) can shift cognitive load from extraneous to germane and (b) can make the science concepts represented in the scientific inscription more explicit to a learner resulting in a shift in the learning to emphasize the science content. This shift will result in the meaningful acquisition and retention of content knowledge.

**Research hypothesis for faded worked examples condition.** Using faded worked examples to scaffold the evaluation and development of a scientific knowledge claim during a 5-DIE lesson is hypothesized to support the acquisition and retention of domain-specific content knowledge. Through faded worked examples, science content can shift from extraneous to germane cognitive load resulting in an increase in the participants' acquisition and retention of science content knowledge.



**Research hypothesis for an interaction effect.** If during a science activity, the learner’s engagement with scientific inscriptions is scaffolded with reflective self-explanation prompts and the learner’s experience with the development and evaluation of a scientific knowledge claim is scaffolded through faded worked examples, then this combined condition is hypothesized to support an increase in the participant’s acquisition and retention of domain-specific content knowledge.

## Method

A quasi-experimental, three-factor design with two between factors and one within factor was used to allow for multiple independent variables to be systematically evaluated (Table 4). The first independent variable was a scientific inscriptions paired with reflective self-explanation prompts in Feature 2 of the 5-DIE lesson (with/without); the second independent variable was a faded worked example strategy for the evaluation and development of scientific knowledge claims (with/without); and the within factor was time (pre-test to post-test to delayed post-test). The dependent variable was content knowledge represented by the participants’ scores on the content knowledge instrument that is described in detail in the content knowledge instrument section below.

Table 4

*Design of the Empirical Study: Three-Factor Design with 2 Between Factors Depicted.*

		<u>Faded Worked Examples</u>	
		Without	With
<u>Self-Explanation Prompts</u>	Without	N = 40	N = 61
	With	N = 44	N = 100

*Note.* Within factor (time) is not depicted.

## **Setting**

The school context for this study was a large suburban school in the southwestern United States. The school population consisted of approximately 3150 students with a 41% minority population. Seventeen percent of the school's population qualified for free/reduced lunch, and 8% had documented disabilities. Participants were enrolled in four Biology Honors, eleven General Biology, and three Inclusionary Biology classes taught by four different teachers (Table 5). Biology Honors is a yearlong course that presents biological concepts in a rigorous manner to academically oriented students. The emphasis in Biology Honors is on the development of critical-thinking skills, research skills, and laboratory techniques. The Biology Honors classes consist primarily of ninth grade participants. General Biology and Inclusionary Biology are both yearlong courses. Each course is designed as a survey of the biological sciences. For both courses, the emphasis of the curriculum is placed on developing skills and techniques that are the basis for making wise career and personal choices in areas related to biological sciences. The Biology and Inclusionary Biology classes consist of both ninth and tenth grade students. The general classes consist entirely of general education students (i.e. students without a documented disability). The inclusionary classes consist of students with documented disabilities (approximately 50% of the students) and general education students. Students with learning disabilities, emotional disorders, or health issues have Individual Education Plans (IEP) and most are enrolled in the Inclusionary Biology course (Table 6).

Table 5

*Description of Teachers*

<b>Teacher</b>	<b>Content Expertise</b>	<b>Years Teaching</b>	<b>Cyberlearning Experience</b>
1	Biological Science	36	Limited
2	Biological Sciences	5	Limited
3	Biological Sciences	4	Limited
4	Biological Sciences	3	None

*Note.* Limited indicates that the teacher has engaged their students in learning science that is mediated by networked computing and communications technologies less than three times per school year.

### Participants

The participants in the study consisted of ninth and tenth grade students (age: 13-16 years; N=245) enrolled in Biology Honors, General Biology, or Inclusionary Biology courses (Table 6). In order to reduce the potential for a teacher effect on the outcomes, the interventions were assigned so each teacher taught each intervention. The anticipated and consented/assented number of participants was 367. However, due to attrition and a school emergency that limited several classes from participating in the posttest, the actual number of participants that were used for analysis was 245. Using a strategy of whole classroom assignment, the initial participants were assigned to one of the four conditions based on teacher and biology course: control condition (N=40), self-explanation condition (N=44), faded worked examples condition (N=61), and combined condition with both self-explanation and faded worked examples (N=100).

Table 6  
*Description of Participants*

Teacher	Honors Students	General Education Students	Students with an Individual Education Plan (IEP)	Total
1	62	0	0	62
2	0	59	28	87
3	0	48	22	70
4	0	21	5	26
Total	62	128	55	245

## Data Source

**Content knowledge instrument.** Acquisition and retention of content knowledge was assessed with a 17-item multiple-choice, researcher-developed content knowledge instrument. Energy transfer in an ecosystem was the science content for the unit. Development of the instrument involved creating a table of specification. A table of specification identifies the content represented in the lesson and the number of questions dedicated to the represented content (Notar, Zuelke, Wilson, & Yunker, 2004). Using Webb's Depth of Knowledge (Webb, 2007), each multiple-choice item was constructed. Finally, the test was subjected to two cycles of expert review and revision in which questions were improved until agreement on the quality of the items was met and the test reliability of the instrument was determined. The following is a description of how the instrument was developed.

Prior to creating the content knowledge instrument, a table of specification (Table 7) was prepared (Notar *et al.*, 2004). Through a detailed evaluation of the lesson, a table of specification was developed to identify the intended science content of the lesson and

the approximate percentage of the intervention dedicated to each strand. The table of specification guided the number of items developed for each content category.

Table 7

*Item Specification for Content Knowledge Instrument*

<b>Science Standards</b>	<b>~% of Intervention</b>	<b># of Assessment Items</b>
Efficiency of energy transfer in an ecosystem	25	4
Evaluate the impact of changes in an ecosystem	30	5
Human Impact	15	3
Transfer of matter and energy through a food web in an ecosystem	30	5

The content knowledge instrument was developed using items from the school district's assessment item pool, as well as modified questions from the following sources: the Program for International Student Assessment (PISA), the National Assessment of Educational Progress (NAEP), and the American Association for the Advancement of Science (AAAS) assessments. The PISA is an international assessment that is designed to measure the literacy of 15-year-old students' in science, mathematics, and reading. NAEP, often called the "Nation's Report Card," is a nationally representative assessment designed to report what students know and can do in core subjects such as science. AAAS, as part of their long-term science education reform initiative Project 2061, provide research-based assessment items to teachers and educational researchers interested in the performance of high school students in science (table 9). In addition to the items selected from these sources, items were developed by the researcher using a

two-tiered format that required a response to a question and a statement of the reasoning for the response (Lee & Liu, 2010). These assessment items were chosen because they were designed to measure content knowledge of high school students of equivalent age to the participants in this study.

Each assessment item was categorized by the researcher and the expert panel (Rew, Becker, Cookston, Khosropour, & Martinez, 2003) using Webb's (2007) depth of knowledge (DOK) in which the test items were considered for both the content assessed (Table 9) and the depth to which the learner is expected to demonstrate understanding of that content (Table 8). A DOK specialist for the school district was consulted for the DOK categorization. To mitigate the potential for a ceiling effect, each content strand had at least one assessment item at DOK levels 1-3. Table 8 provides the DOK level as well as an explanation of the depth of understanding the learner is expected to demonstrate. Using this method, a total of 17 items were selected for the content knowledge instrument (Wyse & Viger, 2011).

Table 8

<i>Webb's Depth of Knowledge Levels (2007)</i>	
<b>Level</b>	<b>Description</b>
1	<i>Recall &amp; Reproduction</i> — Recall a fact, term, or concept.
2	<i>Basic Application of Skills/Concepts</i> — Organize or display data; interpret or use simple scientific inscriptions.
3	<i>Strategic Thinking</i> — Reason or develop a plan to approach a problem; employ some decision-making and justification.
4	<i>Extended Thinking</i> — Perform investigations or apply concepts and skills to the real world that require time to research.

Content validity was established using a panel of four experts, including a university faculty member in science education, a doctoral student in environmental education, a school district curriculum and professional development science specialist, and a Biology II Advanced Placement/International Baccalaureate science teacher. The experts reviewed the items for content and alignment with the lesson. Through a cycle that included review, revisions, and review, questions were modified until consensus on the quality of the items was met. Biology Honors, General Biology, and Inclusionary Biology students not associated with this study participated in a one-group pre-test/post-test design in order to determine the reliability of the content knowledge instrument. The multiple-choice items were scored dichotomously (i.e., “1” for correct answers and “0” for incorrect ones). Analysis of data was conducted using Statistical Package for Social Sciences (SPSS) software, Version 17 to determine the Coefficient Alpha. The reliability of the content knowledge instrument was satisfactory ( $\alpha = .724$ ).

Table 9

*Characteristics of the Content Knowledge Instrument.*

<b>DOK</b>	<b>Content</b>	<b>Origin</b>
1	Efficiency of energy transfer	District Assessment
1	Efficiency of energy transfer	District Assessment
2	Efficiency of energy transfer	Modified from a Practice PISA
3	Efficiency of energy transfer	Researcher Developed KI*
1	Evaluate the impact of changes	AAAS Science Assessment
2	Evaluate the impact of changes	District Assessment
2	Evaluate the impact of changes	AAAS Science Assessment
3	Evaluate the impact of changes	Researcher Developed KI*
3	Evaluate the impact of changes	District Level Assessment
1	Human Impact	Researcher Developed
2	Human Impact	Researcher Developed
3	Human Impact	Modified NAEP Practice
1	Transfer of matter & energy	District Assessment
1	Transfer of matter & energy	Modified NAEP Practice
2	Transfer of matter & energy	District Assessment
3	Transfer of matter & energy	Researcher Developed KI*
3	Transfer of matter & energy	AAAS Science Assessment

*Note.* \*KI refers to knowledge integration two-tiered assessment format (Lee & Liu, 2010)

### Statistical Analyses

Analysis of data involved a three factor mixed model ANOVA. Content knowledge, represented by the participants' scores on the content knowledge instrument was the dependent variable. The research table (Table 10) aligns the study's research



questions, the intervention related to the research question, the measure of assessment and the analysis used to determine effect. Question 4 is not a question that can be answered statistically and, therefore, will be discussed in Chapter 5.

Table 10

*Research Table.*

<b>Question</b>	<b>Intervention</b>	<b>Measure(s)</b>	<b>Analysis</b>
What is the effect of learning with inscriptions paired with self-explanation prompts during evidence collection in a 5-DIE lesson on the acquisition and retention of domain-specific content knowledge?	Inscriptions paired with self-explanation prompts during evidence collection	Pretest, posttest, delayed posttest – Content Knowledge Instrument	Three factor mixed model ANOVA
What is the effect of faded worked examples for the evaluation and development of scientific knowledge claims during a 5-DIE lesson on the acquisition and retention of domain-specific content knowledge?	Evaluation of faded worked example and the development of scientific knowledge claim	Pretest, posttest, delayed posttest - Content Knowledge Instrument	Three factor mixed model ANOVA
Is there an effect related to learning with inscriptions paired with self-explanation prompts and evaluation and development of scientific knowledge claims on the acquisition and retention of domain-specific content knowledge?	Inscriptions paired with self-explanation prompts during evidence collection & Evaluation of faded worked example and the development of scientific knowledge claim	Pretest, posttest, delayed posttest - Content Knowledge Instrument	Three factor mixed model ANOVA

## Procedure

The study consisted of three phases (Figure 4.). In the first phase, participants completed the pretest content knowledge instrument. This was conducted during week fifteen of the semester (one week before the experimental phase). During the experimental phase, participants completed the 5-DIE lesson (detailed below in the learning environment and interventions section). This phase began during week sixteen of the semester. Participants were assigned randomly to one of the four conditions: (1) control condition, (2) self-explanation prompts condition, (3) faded worked examples condition, and (4) both combined condition.

The amount of time allotted to complete the lesson was five 50-minute class periods. Immediately after completing the fifth 50-minute class period, participants completed the post-test content knowledge instrument. The final phase took place five weeks after the experimental phase when participants completed the delayed posttest content knowledge instrument.

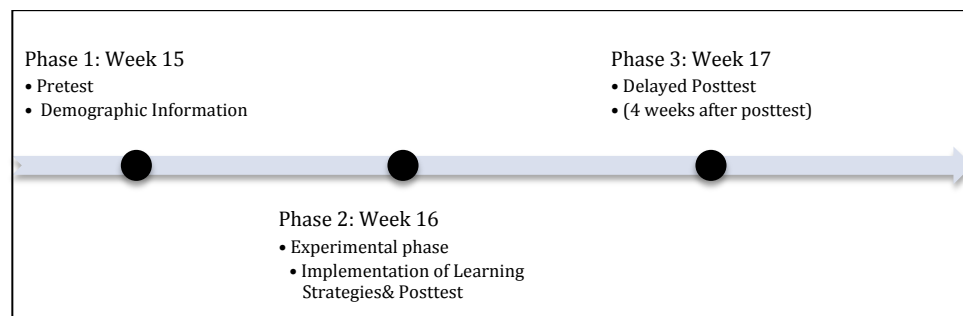


Figure 4. Implementation timeline.

**The learning environment and interventions.** The lesson was presented in a blended learning environment in which network-computing resources were used to support face-to-face classroom instruction. The lesson was designed using SoftChalk software. SoftChalk is an authoring tool for online lessons that does not require code writing. Once a lesson is created in SoftChalk, it can be packaged for deployment in a Learning Management System (LMS). The LMS used to deliver the lesson was a free software platform called MOODLE (Modular Object-Oriented Dynamic Learning Environment) that is hosted by a server located at UNLV. All content for the lesson was delivered using the LMS. As the participants worked through the 5-DIE lesson, they completed a formal product called a Research Brief. Participants recorded their thinking, analysis, reflection, and synthesis in the Research Brief while completing the lesson. Sentence starter prompts embedded in the Research Brief intended to guided the participants in the making their thinking explicit in a manner to support the development of a rich conceptual understanding.

Each of the participating teachers involved in enacting the interventions had a separate section in the LMS dedicated to their class, and this section was populated with their students. Prior to enacting the interventions, each teacher completed the lesson and discussed how they envisioned implementing the lesson with their students. In the tradition of Design-Based Research, the implementation of this designed intervention took place in a real-world, naturalistic setting (Barab & Squire, 2004). This means the teachers addressed the individual questions and needs of the participants, assisted students with implementing the technology, and engaged in conversations generated by the participants while completing each of the interventions.

**5-DIE lesson.** In the section that follows, examples of the five different features from the 5-DIE lesson (the control condition) are provided. During the lesson, participants explored the effect human activity or climate change could have on organisms in the same and neighboring ecosystems. The changes in the ecosystems were evaluated with energy flow diagrams called food webs. The specific relationship evaluated was the correlation between the number of organisms and amount of available energy that could be transferred to the next trophic level. The participants worked in groups of two assigned by their teachers and they shared one laptop computer.

As participant completed specific activities during the 5-DIE lesson, they were instructed to respond to certain questions or prompts. They recorded their individual answers in a document called a “Research Brief.” Through prompting with narrative text provided in the Research Brief template (e.g., “Look at the model and explain to yourself and your partner what the following statement means: The arrows represent the transfer of energy from one trophic level to the next.”), the participants were encouraged to discuss the activities within their groups. However, each participant completed an individual Research Brief. There were four forms of the Research Brief template, one for each condition. The Research Brief template for the control condition without any additional learning strategies (Figures 12 & 14). The Research Brief template for the self-explanation condition contained self-explanation prompts paired with each inscription (Figure 13). The Research Brief template for the faded worked example condition contained four worked example claim statements each with progressively less information in each example (Figures 15-17). The Research Brief for the combined condition contained both self-explanation prompts paired with each inscription and faded

worked examples. Regardless of the condition to which they were assigned, the participants were instructed to complete each of the five features presented in the 5-DIE lesson (Table 11).

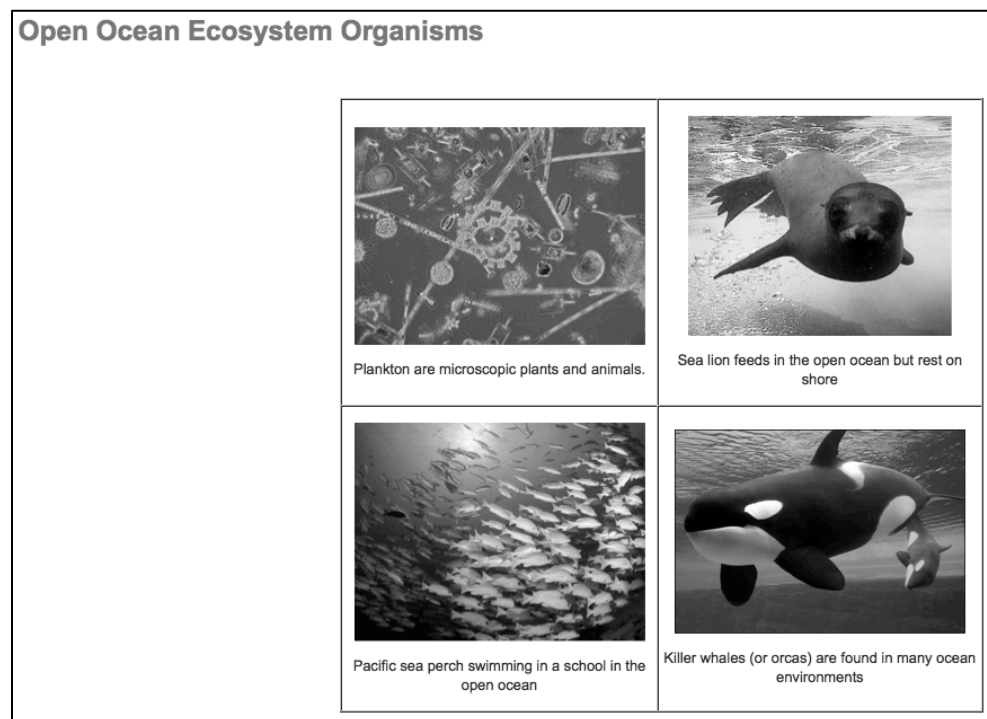
Table 11

*Overview of the Elements & Activities for Each Feature of the Control Condition.*

	Elements	Activities
Feature 1	<ul style="list-style-type: none"> <li>• Multimedia intended to elicit an initial response to the scientifically oriented question.</li> <li>• Reflective Starter Prompts intended to elicit prior conceptions.</li> <li>• Planning Starter Prompts intended to develop self-regulatory skills.</li> </ul>	<ul style="list-style-type: none"> <li>• Look at, read about, and discuss the marine organism in the food web used in the lesson.</li> <li>• View several videos depicting the energy transfer</li> <li>• Discuss prior understanding of the topic with peers.</li> </ul>
Feature 2	<ul style="list-style-type: none"> <li>• Collect evidence related to the science content of the scientifically oriented question.</li> <li>• Partially worked example of the scientific inscription</li> <li>• Activity Starter Prompts intended to engage participants in specific explicit evidence collection and development of inscriptions.</li> <li>• Reflective Starter Prompts to elicit the learner's understanding of the relationship that exists between their prior understanding and the evidence collected.</li> </ul>	<ul style="list-style-type: none"> <li>• Manipulate the number of organisms represented in a simulation based on human decisions and the consequences of climate change.</li> <li>• Record observation in a scientific inscription.</li> <li>• Discuss and record responses to a variety of starter prompts.</li> </ul>
Feature 3	<ul style="list-style-type: none"> <li>• Analyzing evidence and using it to generate an explanation (also called a claim) about the scientific ideas of the lesson.</li> <li>• Scientific Knowledge Claim Starter Prompts</li> </ul>	<ul style="list-style-type: none"> <li>• Prompts to analyze the evidence as it is represented in the energy flow diagrams (food webs).</li> <li>• Prompt to make a claim statement for the five scenarios presented in the lesson.</li> </ul>
Feature 4	<ul style="list-style-type: none"> <li>• Multimedia feature intended to elicit personal reflection on how the participant's ideas compare to the accepted scientific ideas</li> <li>• Reflective Starter Prompts intended to elicit the participant's understanding of the relationship that exists between their prior understanding, their scientific knowledge claims, and the known scientific understanding.</li> </ul>	<ul style="list-style-type: none"> <li>• Look at inscription and read about and discuss the explicit consequences of human decisions and climate change on the flow of energy in an ecosystem.</li> <li>• View several videos, which depict the energy transfer (eating) among trophic levels.</li> <li>• Respond to a variety of starter prompts, which require reflection about how their ideas presented as a scientific claim statement align with accepted scientific ideas.</li> <li>• Reflect on and revise their scientific claim statements.</li> </ul>
Feature 5	<ul style="list-style-type: none"> <li>• Participants present their revised scientific claim statements to their peers and teachers.</li> <li>• Participate in collaborative argumentation where evidence, claims and relationships are discussed.</li> </ul>	<ul style="list-style-type: none"> <li>• Respond to a variety of starter prompts, which require reflection about how their ideas presented as a scientific claim statement aligns with their peers and teachers ideas.</li> <li>• Revise their scientific claim statements.</li> </ul>

**Feature 1.** Feature 1 of the 5-DIE lesson in all conditions was focused on the scientific question, “How do humans and climate change impact energy flow in an

ecosystem?” After a rich, multimedia event that included videos, pictures, and text designed to prompt prior knowledge and pique interest (Figures 5 & 6), the participants responded to activity prompts designed to elicit their initial ideas related to the scientifically oriented question (e.g., “Based upon on the various videos depicting the transfer of energy in the Pacific Ocean, we think that a change in one group of organisms may impact another group of organism in the following ways... because...” (Figures 7).



*Figure 5.* A rich multimedia event includes images (shown) and video (not shown) from Feature 1 for all conditions.

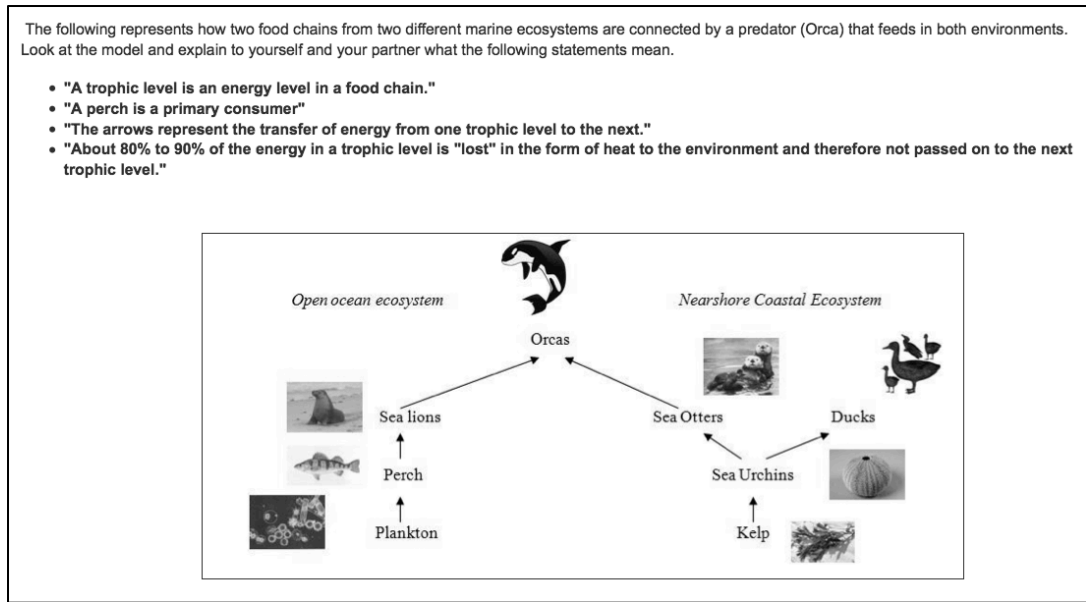





Figure 6. Learners are prompted to make explicit their understanding about science concepts through discussion with their partner.

		
Fishing for Pacific sea perch.	Climate change prediction model for the impact of a 4°C change in global temperature.	Humans build hotels and homes on nearshore environments where ducks nest and feed.

**Research Brief Activity:**

1. Based upon on the various videos depicting the transfer of energy in the Pacific Ocean, we think that a change in one group of organisms may impact another group of organism in the following ways... because....
2. We think a trophic level is related to energy in the following way...
3. We think the statement, "80% - 90% of energy is not transferred to the next trophic level" means...
4. I think that if there is an increase in the food that the organisms eat, the population will... because...
5. We think human activities will impact marine ecosystem food webs in the following ways...
6. We think climate change will impact marine ecosystem food webs in the following ways...
7. We think the change in number of organism in a population is related to...
8. Watching videos has also made us wonder about...

Figure 7. Feature 1 Research Brief activity for all conditions, control and experimental.

**Feature 2.** Feature 2 of the lesson involved a set of activities in which participants were required to collect evidence related to “How do humans and climate change impact energy flow in an ecosystem?” The focus of Feature 2 is evidence collection based on the manipulation and output of a Forio model (Figure 9). Forio is a company that allows unlimited and free access to Web-based, interactive system dynamic models that have been built with Stella software. System dynamics is an approach to understanding the behavior of complex systems over time that uses mathematical modeling to understand complex issues associated with a specific system (Morrison, Rudolph, & Carroll, 2013). System dynamic models use feedback loops and time delays to model how changes in one variable in the system may affect the system as a whole. The energy flow in an ecosystem simulation (Forio Online Simulations, 2011) was built in Forio and allowed participants to evaluate energy flow among trophic levels in a near shore and open ocean food web as it relates to the following five scenarios:

- 1) The overfishing of perch in the open ocean.
- 2) The destruction of nesting and feeding habitat of sea ducks.
- 3) The effect of an increase of ocean temperatures associated with global climate change on kelp population.
- 4) The effect of an increase of ocean temperatures associated with global climate change on the phytoplankton population.
- 5) The effect of acidification associated with carbon emissions on sea urchin fertilization.




For each of the scenarios, the participants were provided with a description and images related to the scenario (Figure 8). The participants then manipulated the number of organisms represented in the Forio simulation (Figure 9) by adjusting the slider bar below the population. For example, in scenario #1, the number of perch is reduced to below 500,000 in the population. Then the participants in the Research Brief recorded the results of the simulation runs. Participants were provided with a scientific inscription (Figure 10) in their Research Brief to organize and record their observations. Examples of Research Brief activities specific to the learning strategies explored in this study are provided in the intervention sections of this chapter.

**Task 1: How does human activity impact a food web?**

**Simulation #1**

During the early 1990's a study revealed that the sea otter population near the coast of Alaska was declining at approximately 25% per year. Scientists found that there was no widespread disease in the otters and no decrease in the otters' food supply. In fact, the population of sea urchins, the otters' main food source in the near shore coastal ecosystem, was larger than ever. In a seemingly unrelated study, another group of scientists documented a large decrease in the population of ocean perch living in a nearby ocean ecosystem – the offshore open ecosystem. (Source: Science and Sustainability textbook) Humans use fishing boats in fleets to net and capture large amounts of perch each year.



*Figure 8.* Task 1 scenario related to the overfishing of perch in the open ocean.

### Simulation #1

- In the first simulation you will investigate the impact a decrease in perch do to overfishing would have on the open ocean and nearshore ecosystems.
  - Reduce the number of perch to less than 500K (500,000) but greater than zero in the open ocean ecosystem by sliding the bar to the left.
- Run the simulation, look at the bar graph carefully, determine how the populations changed, then using up arrows, down arrows, or a straight line to represent what happened to all the populations in your graphic organizer after running the simulation.
- Complete the graphic organizer and starter prompts.
- Reset the simulation.
- Continue on to the next simulation.

Figure 9. Image of the Web interface for the Forio Model. (Forio Online Simulations, 2011).

### Research Brief Activity:

- Run the simulation
- Look at the bar graph carefully, determine how the populations changed.
- Then using up arrows, down arrows, or a straight line to represent what happened to all the populations in your graphic organizer.

NOTE: Top right line is for Sea Otters and Second Right Line is for Ducks


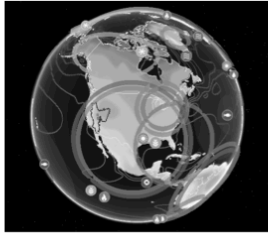

The above graphic organizer is found in your Research Brief. Record your observations using arrows on each of the lines to represent the change in population.

Then click on the "DragNDrop Activity" below to report your results.

Figure 10. Image of the prompting provided to participants for using the scientific inscription in their Research Brief.

**Feature 3.** The claim statement in the lesson is structured based on Toulmin's Argument Pattern – TAP (Toulmin, 1958). There are six components of an argument with the first three – claim, data, and warrant – considered essential components to any argument (Toulmin, 1958). The claim is the assertion or position made in the argument and is also the merited conclusion made as a statement of fact. The claim is supported by data, which is evidence used to establish merit for the claim.

For Feature 3 of the lesson, participants analyzed the evidence they collected and used it to generate an explanation in the form of a claim statement about the effect humans and climate change may have on energy flow in an ecosystem. The claim statement included a statement of the evidence, a claim (i.e., a conclusion) drawn from the evidence, and a description of the relationship between the claim and evidence. Figure 11 is a screenshot of a scaffold called a DragNDrop where the participants match the names of the argument components to the specific parts of the claim statement.

		
Fishing for Pacific sea perch.	Climate change prediction model for the impact of a 4°C change in global temperature.	Humans build hotels and homes on nearshore environments where ducks nest and feed.

A scientific claim statement has three components or parts: Evidence, Claim, and Relationship. Observations resulting in data collection are the basis of evidence. When data is analyzed it may provide **evidence** to support a conclusion or **claim** for the investigation. In a scientific claim statement the **relationship** between the claim and evidence must be explained.

Read the following claim statement, identify the evidence, claim, and relationship statements, then use the "DragNDrop" activity to record your results.

When the number of perch was decreased in our simulation the sea lion and sea otter populations decreased and there was an increase in the plankton, sea urchin, duck, and kelp population, therefore I **claim that overfishing of perch in the open ocean impacts the energy available in the food web** because when humans remove the perch for humans to eat they remove the energy available to other animals in the food web causing changes in the ecosystems.

DragNDrop Activity

*Figure 11.* Feature 3 screenshot where the components of an argument are described and participants complete a DragNDrop activity related to the components.

**Feature 4.** The accepted scientific understanding about energy flow in an ecosystem is presented in Feature 4 of the lesson. Like Feature 1, the presentation of the content in Feature 4 is also media rich with videos, animations, diagrams, and text. In this feature, participants were given the opportunity to compare their claim statements to the scientific understanding. This was meant to be a reflective component in which the participants had the opportunity to compare and contrast their explanations for? to the accepted scientific explanations as well as make revisions to their claim statement in order to reflect their evolving understanding. This allowed participants to prepare for the final feature of the lesson in which they presented their revised claim statements to their peers and teacher.

**Feature 5.** Finally, in Feature 5 of the lesson, participants shared and justified their claim statements among their peers and with their teacher in a collaborative discussion referred to as Research Council. This provided further opportunity for evaluation of ideas through collaborative discourse. The culminating activity of the lesson allowed the participants to reflect on the scientific question of Feature 1 and synthesize their understanding by using evidence to compare and contrast their ideas with their peers and teacher. Once Research Council was complete, the participants were prompted in their Research Brief to describe how their ideas about the scientific questions were similar to and different from their peers. They were also prompted to reflect on how their thinking had changed as a result of their engagement with the lesson.

**Modifications for experimental conditions.** The two interventions central to this research study were scientific inscriptions paired with self-explanation prompts and faded worked examples for the evaluation and development of a claim statement. The scaffolding of the scientific inscriptions was specific to Feature 2 of this lesson while the scaffolding of the claim statement was specific to Feature 3. Each learning strategy is discussed in the following sections.

**Intervention #1: Inscriptions paired with self-explanation.** A scientific inscription that was paired with self-explanation prompts was provided during data collection in Feature 2 of the lesson in two of the experimental condition (with self-explanation prompts and the combined condition) . The self-explanation prompts were used to elicit reflection and explanation. A prompt is a structured, explicit start to a constructed response that directs the participant to engage in evaluation and use of the inscriptions as well as the data collected (Kern *et al.*, in press). In response to the

scenarios (described previously in the control condition section), using the provided scientific inscription, the participants recorded the effect a change in one population could have on other populations in the simplified food web. There were a total of five scenarios, each of which had its own inscription. The Research Brief activity in Feature 2 for scenario #1 is depicted in Figure 12. The Research Brief activity modified for the self-explanation prompts condition is shown in Figure 13. When comparing the two the Research Brief activities from each condition, the notable difference is the explicit prompting for self-explanation related to the science concepts represented by the two different types of arrows in Figure 13.

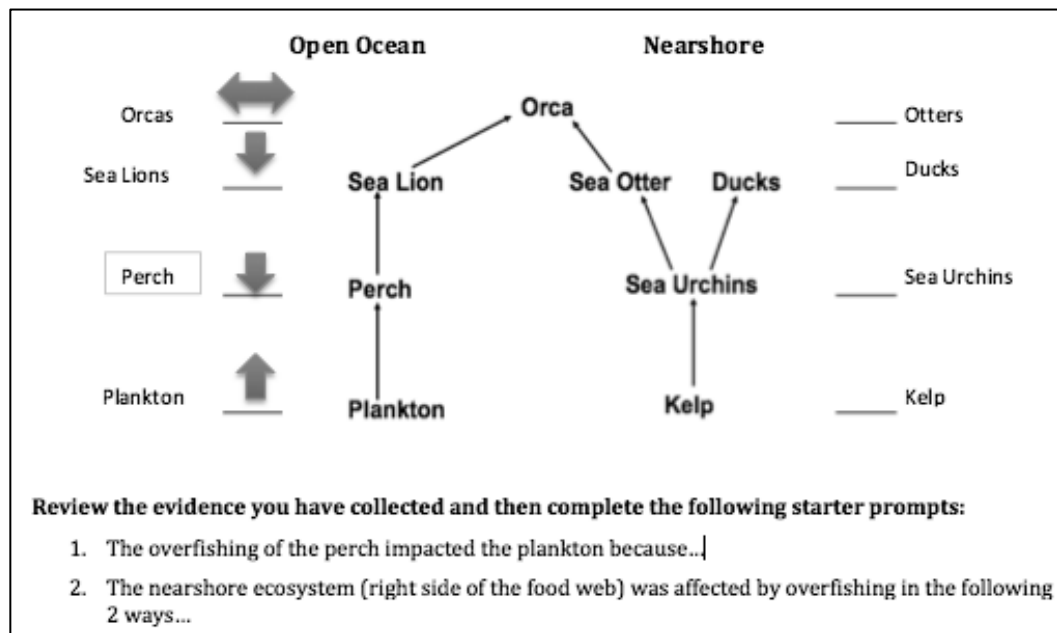


Figure 12. Control condition for scenario #1 in Feature 2 of the lesson.

**Open Ocean**
**Nearshore**

**Review the evidence you have collected and then complete the following starter prompts:**

1. Two reasons the graphic organizer above is helpful in data collection are...
2. The graphic organizer helped me...
3. In the graphic organizer there are *two* different types of arrows that represent *two* different science concepts. Explain to your partner what each arrow represents then describe them below.
  - a. Bold (↑/↓) arrows represent...
  - b. Thin arrows (Plankton → Perch) represent...
4. The overfishing of the perch impacted the plankton because...
5. Two ways the nearshore ecosystem (right side of the food web) was impacted by overfishing include...

*Figure 13.* Screenshot of the inscription paired with self-explanation prompts from scenario #1 in Feature 2 of the lesson. This figure illustrates the scientific inscription paired with self-explanation prompts intervention for scenario #1 in the self-explanation prompts and combine conditions.

### **Intervention #2: Faded worked example learning strategy for science**

**knowledge claims.** The development of the scientific knowledge claim was scaffolded with a series of worked examples in which components of the claim statements were removed, or faded, leaving the participants to complete the remaining tasks. Each scientific knowledge claim is based on the scenarios (described previously in the control

condition section), where the participants are asked to develop a claim statement about the effect a change in one population could have on other populations in the simplified food web. In the Research Brief for the 5-DIE lesson (the control condition, Figure 14), participants' interactions with collected evidence are not scaffolded with faded worked examples. In Feature 3 of the worked examples condition (Figures 15-17), however, participants are guided through the development of claim statements through faded worked examples. When comparing the two the Research Brief activities from each condition, the notable difference is the explicit modeling of the claim statement depicted in Figures 15.

<p><b><u>Your Scientific Claims</u></b></p> <p><b>Claim #1: How does <u>human activity</u> impacts a food web?</b></p> <p>As evidenced by...</p> <p>Human activity may impact populations in a food web by...</p> <p>because...</p> <p><b>Claim #2: How does <u>climate change</u> impacts a food web?</b></p> <p>As evidenced by...</p> <p>Climate change may impact populations in a food web by...</p> <p>because...</p>
--

*Figure 14.* Represent the Research Brief activity for Feature 3 of the lesson that is not scaffolded with faded worked examples. Participants were provided with sentence starter prompts to scaffold the development of their scientific knowledge claims.



Based on the scenarios and the evidence collected in Feature 2 of the lesson, a series of faded worked examples were developed to scaffold the participants' development of a claim statement. There were two parts to the faded worked examples: the worked example, where all components of the claim are modeled, and the fading of the component over time, which is designed to reduce the expertise reversal effect. The first worked example (see Table 12) included a description of the individual components of a claim statement (i.e., evidence, claim, and relationship) and a sample claim statement developed from the evidence collected from Feature 2 of the lesson with each component identified (Figure 15).

**Your Scientific Claims**

A scientific claim statement has three components or parts: Evidence, Claim, and Relationship. Observations resulting in data collection are the basis of evidence. Evidence is a statement of what you saw happen in the model. When data is analyzed it may provide **evidence** to support a conclusion or **claim** for the investigation. In a scientific claim statement the **relationship** between the claim and evidence must be explained.

The following is an example of a scientific claim statement. Each component of the scientific claim statement is written in a different font to help you see the structure.

- Evidence
- *Claim*
- Relationship

When the number of perch was decreased in our simulation the sea lion and sea otter populations decreased and there was an increase in the plankton, sea urchin, duck, and kelp populations, therefore I *claim* that overfishing of perch in the open ocean impacts the energy available in the food web because when humans remove the perch for humans to eat they remove the energy available to other animals in the food web causing changes in the ecosystems.

*Figure 15.* Screenshot of the first worked example where a description of the individual components of a claim statement (i.e., evidence, claim, and relationship) and a sample claim statement are provided. This figure illustrates the first worked example provided to the participants for the faded worked example and combine conditions.

A second claim statement worked example was provided and the participants were required to identify each component of the claim statement (Figure 16). A final worked example provided participants with two of the three components of a scientific claim statement and the participants were required to write out the missing components of the claim statement (Figure 17).

**The following is a scientific claim statement about human impact on a food web. Read the claim statement then underline each component of a claim statement with the assigned color.**

- Evidence (Blue)
- Claim (Green)
- Relationship (Red)

Human activity impacts population in a food web when they build homes and hotels where ducks nest and feed because there is an increase in the number of ducks eating sea urchins in the nearshore environment causing a change in available energy for other populations. We saw this in the model when the duck population was increased the sea urchin, sea otter, plankton and sea lion populations' decrease and the kelp and perch populations increased.

*Figure 16.* Screenshot of the second worked example where the participants identify each component of the argument. This figure illustrates the second worked example provided to the participants for the faded worked example and combined conditions.

**The following is a scientific claim statement about human impact on a food web. Read the claim and reason parts of the statement then complete the statement by adding the evidence that supports the claim and relationship.**

I claim that an increase in global temperatures impacts energy transfer in an ecosystem because kelp live in cold waters and warms temperatures leads to a decrease in the number of kelp reducing the amount of available energy in the food web. This evidenced by...

*Figure 17.* Screenshot of the final worked example where participants completed the claim statement by stating the evidence. This figure illustrates the final worked example provided to the participants for the faded worked example and combine conditions.

The participants are then given the same sentence starter prompts provided in the control condition (Figure 14) and are asked to develop their own claim statements for the fifth scenario.

### **Summary**

A three factor mixed model ANOVA was used to evaluate the effects of the learning strategies on the acquisition and retention of domain-specific content knowledge of 245 high school biology participants. The two between factors each had two levels (with & without) and are described by the following experimental conditions: (1) control condition, (2) self-explanation prompts condition, (3) faded worked examples condition, and (4) both combined condition. Acquisition and retention of content knowledge was assessed with a 17-item multiple-choice content knowledge instrument in a pretest-posttest-delayed posttest design.

Table 12

*Faded Worked Example for the Claim Statement: 5-DIE Lesson—Feature 3*

Faded Example	Faded Worked Example	Scenario Concept	Participant Actions
1	<p>When the number of perch was decreased in our simulation the sea lion and sea otter populations decreased and there was an increase in the plankton, sea urchin, duck, and kelp populations, <i>therefore I claim that overfishing of perch in the open ocean impacts the energy available in the food web because when humans remove the perch for humans to eat they remove the energy available to other animals in the food web causing changes in the ecosystems.</i></p>	Overfishing	<p>The <u>evidence</u> is underlined, the <i>claim</i> is italicized, and the <b>reason</b> is boldface.</p> <p>Identify and discuss each component of the claim statement.</p>
2	<p>Human activity impact populations in a food web when they build homes and hotels where ducks nest and feed because there is an increase in the number of ducks eating sea urchins in the nearshore environment causing a change in available energy for other populations. We saw this in the model when the duck population was increased the sea urchin, sea otter, plankton and sea lion population decrease and the kelp and perch populations increased.</p>	Habitat destruction	<p>Identify each component of the claim statement independently.</p>
3	<p>I claim that an increase in global temperatures impacts energy transfer in an ecosystem because kelp live in cold waters and warms temperatures leads to a decrease in the number of kelp reducing the amount of available energy in the food web. The evidence to support this claim is...</p>	Increase of ocean temperatures	<p>Identify the claim and relationship statements then provide the evidence.</p>
4	<p>As evidenced by... Climate change may impact populations in a food web by... because.....</p>	<p>Increase of ocean temperatures or Acidification of the ocean</p>	<p>Develop a claim statement for one of the two remaining scenarios.</p>

## **Chapter 4 Results**

This study addressed the effects of two learning strategies on the science content knowledge of ninth- and tenth-grade students enrolled in a biology course at a large, comprehensive, urban high school. The first learning strategy, self-explanation prompts paired with scientific inscriptions, was designed to shift the mental effort (i.e., cognitive load) from superficial engagement in scientific inscriptions (e.g., graphs, diagrams, data) to meaningful engagement by providing sentence starter prompts designed to promote reflective self-explanation. This learning strategy was designed to reduce passive engagement in the scientific inscription and promote reflective self-explanation of the content represented in the scientific inscription. The second learning strategy involved the use of faded worked examples to meaningfully engage learners in the evaluation and development of a scientific claim statement. Faded worked examples are a progression of detailed problem solutions where the processes associated with solving a problem are made explicit to the learner and the problem solutions and explanations are systematically removed as the learner proceeds in developing a problem solving skill (Crippen & Earl, 2007). The faded worked example learning strategy was meant to engage learners in the critical evaluation of several expert claim statements where subsequent steps are faded or removed until learners are responsible for developing their own claim statement(s). The interrelationship that exists between a scientific claim statement and a scientific inscription used for evidence collection may be significant in understanding the science content presented. The purpose of this study was to advance education theories and inform instructional design by determining whether these learning strategies, when

embedded in the 5-Featured Dynamic Inquiry Environment (5-DIE), significantly affect the acquisition and retention of content knowledge.

### **Research Questions**

- 1) What is the effect of learning with inscriptions paired with self-explanation prompts during evidence collection in a 5-DIE lesson have on the acquisition and retention of domain-specific content knowledge?
- 2) What is the effect of faded worked examples for the evaluation and development of scientific knowledge claims during a 5-DIE lesson have on the acquisition and retention of domain-specific content knowledge?
- 3) Is there an effect related to inscriptions paired with self-explanation prompts and use of faded worked examples for the scientific knowledge claims on the acquisition and retention of domain-specific content knowledge?
- 4) How can the results of this study contribute to the further innovation of 5-DIE?

### **Study Overview**

The school context for this study was a large, suburban school in the southwestern United States. Participants were enrolled in four Biology Honors, eleven General Biology, and three Inclusionary Biology classes taught by four different teachers. Data were collected in three phases. In the first phase, one-week before the experimental phase (week fifteen of the semester), participants completed the content knowledge instrument as a pretest. For the experimental phase, starting one week later, participants began the 5-DIE lesson. The participants were assigned to two independent variables

(self-explanation prompt and faded worked examples) each with two levels (with and without) which resulted in four experimental conditions: 1) neither self-explanation prompts nor faded worked examples learning strategies ( $SE_{(w/o)}$ ,  $FWE_{(w/o)}$ ), 2) with self-explanation prompts learning strategy without faded worked examples learning strategy ( $SE_{(w)}$ ,  $FWE_{(w/o)}$ ), 3) with faded worked examples learning strategy without self-explanation prompts learning strategy ( $SE_{(w/o)}$ ,  $FWE_{(w)}$ ), and 4) with both self-explanation prompts and faded worked examples learning strategies ( $SE_{(w)}$ ,  $FWE_{(w)}$ ) (Table 4 p.57).

Although 639 students participated in the lessons designed for this study, only 245 consented/assented to participate in the research and successfully completed all components of the study. Therefore, the sample included 245 participants. Internal Review Board (IRB) and school district policy require the minor's involvement in this study be completely voluntary. Participant data was accessed only after they had returned signed parent permission and student assent forms. If a student did not return signed parental consent and student assent forms or if any data sources were missing (pretest, posttest, delayed-posttest), they were not included as participants. Results were visually examined for missing data. The removal of students from the study due to missing data produced variation in the number of participants within each condition in the experimental design. Attrition was also related to the voluntary nature of the study where participants could elect to withdraw from the study at any time. In addition, a school emergency prevented a large number of students from completing the posttest.

A quasi-experimental, three-factor design with two between factors and one within factor was used to allow for multiple independent variables to be systematically evaluated (Table 4 p. 57). The first independent variable involved the inclusion of a

scientific inscription paired with reflective self-explanation prompts which was included in Feature 2 of the 5-DIE lesson; the second independent variable involved the use of the faded worked example learning strategy for the evaluation and development of scientific knowledge claims which was included in Feature 3 of the 5-DIE lesson; and the within factor was time (pretest to post-test to delayed post-test). Each quadrant in the experimental design represents both independent variables (self-explanation prompts (SE) and faded worked examples (FWE) and the level of the independent variables (with or without). Each of the quadrants will be referred to as a condition based on the inclusion of the independent variable. For example, the self-explanation condition is the quadrant with self-explanation prompts and without faded worked examples ( $SE_{(w)}$ ,  $FWE_{(w/o)}$ ). The 245 participants were enrolled in one of three state-mandated biology courses taught by four different teachers and included 62 students enrolled in Biology Honors, 128 students enrolled in General Biology, and 55 students with documented disabilities (Table 6, p. 60). The average age of the participants was 14.3 years. The attrition of students resulted in a wide variety in the number of participants in each condition (Table 4, p. 57): control condition ( $N=40$ ), self-explanation prompts condition ( $N=44$ ), faded worked examples condition ( $N=61$ ), and combined condition ( $N=100$ ) for a total of 245 participants.

## **Analysis**

Analysis for the integrity of each intervention – the level to which the participants engaged in the interventions – was determined by completing a two person blind review of the participants' Research Briefs and a follow up conversation with the teachers responsible for implementation. The accepted characteristics of a Research Brief that



indicated the participant engaged in the interventions was: 1) the participant had to have completed 75% of the Research Brief, and 2) 75% of the activities related to the interventions had to be completed. After the Research Briefs were coded there was a follow up conversation each teacher were a conversation pertaining to participant engagement in completing the interventions and the efforts the teachers put forth to get the participants to complete the Research Briefs.

Table 13 shows percent of participants who engaged in the each of the interventions. Ninety percent of the participants assigned to the control ( $SE_{(w/o)}$ ,  $FWE_{(w/o)}$ ) condition engaged in the Research Brief and 89% of the participants in the self-explanation prompts ( $SE_{(w)}$ ,  $FWE_{(w/o)}$ ) condition engaged in the Research Brief activities as well as the self-explanation prompts learning strategy. While 78% of the participants in the faded worked example ( $SE_{(w/o)}$ ,  $FWE_{(w)}$ ) condition and 77% of the participants in the combined ( $SE_{(w)}$ ,  $FWE_{(w)}$ ) condition engaged in the Research Brief activities including the self-explanation prompts and faded worked example learning strategies. The percentage of participants engaging in the Research Brief and the learning strategies indicates the interventions have integrity.

Table 13

*Percent of Participants who Engaged in Each Intervention.*

		<b>Faded Worked Examples</b>	
		<b>Without</b>	<b>With</b>
<b><u>Self-Explanation Prompts</u></b>	<b>Without</b>	90%	78%
	<b>With</b>	89%	77%

A follow up interview with the teachers implementing the interventions indicated the participants required little to no additional encouragement to complete the assignment. The few participants who did struggle to stay on task and engaged were worked with on a one on one basis and then were encouraged to record their ideas in the Research Brief. The teachers also indicated that helping participants engage was not difficult because the majority of participants were on task.

Analysis of data was conducted using Statistical Package for Social Sciences (SPSS) software, Version 17 using both descriptive and inferential statistics to examine the data for the three factor mixed model ANOVA. Content knowledge, which was represented by the participants' scores on the content knowledge instrument, served as the dependent variable. The collective results for all participants (N=245) are presented followed by the presentation of the results for the conditions.

The statistical test yielded no significant difference for the combined condition ( $SE_{(w)}$ ,  $FWE_{(w)}$ ) over time,  $F_{(1,99)} = 2.23$  [MSE = 8.63],  $p > .05$ , no significant difference for the self-explanation prompts condition ( $SE_{(w)}$ ,  $FWE_{(w/o)}$ ) over time,  $F_{(1,43)} = .236$  [MSE = .913],  $p > .05$ , no significant difference for the faded worked example condition ( $SE_{(w/o)}$ ,  $FWE_{(w)}$ ) over time,  $F_{(1,60)} = .99$  [MSE = 3.83],  $p > .05$ . In addition, the statistical test yielded no significant difference for the combined condition ( $SE_{(w)}$ ,  $FWE_{(w)}$ ),  $F_{(1,241)} = 1.08$  [MSE = 22.37],  $p > .05$ , no significant difference for the self-explanation prompts condition ( $SE_{(w)}$ ,  $FWE_{(w/o)}$ ),  $F_{(1,241)} = .010$  [MSE = .199],  $p > .05$ , no significant difference for the faded worked example condition ( $SE_{(w/o)}$ ,  $FWE_{(w)}$ ),  $F_{(1,241)} = 2.189$  [MSE = 45.18],  $p > .05$ . The statistical test of homogeneity of variance indicated that variances in each condition were equal.

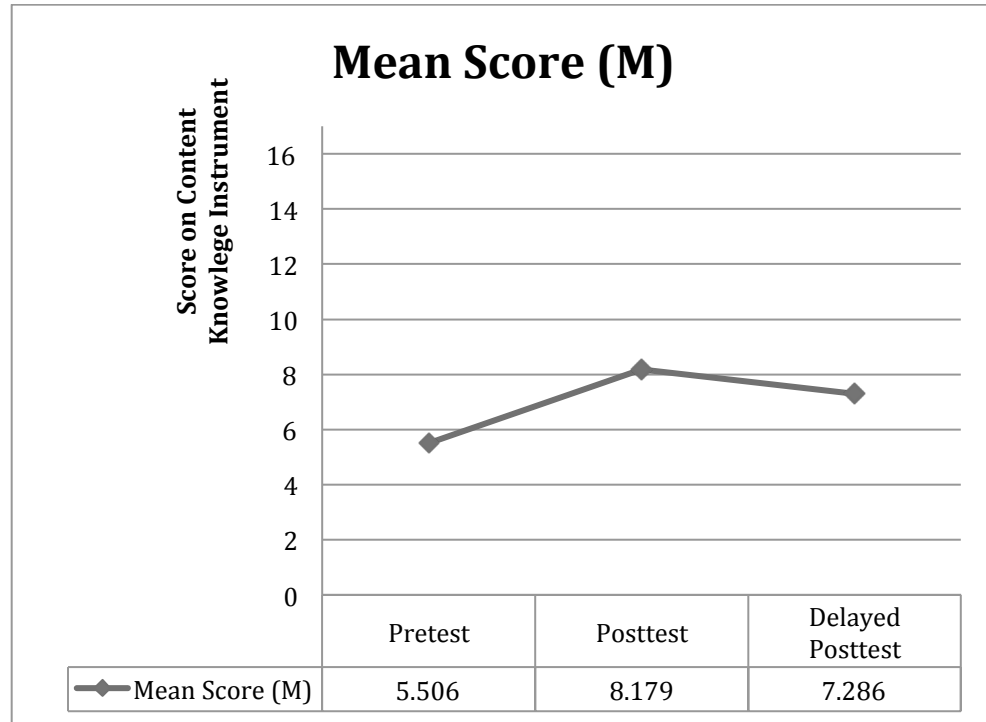
The statistical analysis for the pretest, posttest, and delayed posttest yielded a significant difference,  $F_{(1,241)} = 98.1$  [MSE = 3.80],  $p < .05$ . A Posthoc Tukey HSD follow-up revealed that participants performed the best overall on the posttest, indicating an acquisition of content knowledge. The delayed posttest scores were significantly lower than the posttest scores yet significantly higher than the pretest scores indicating retention of content knowledge.

The mean score for all conditions on the content knowledge instrument between pretest and posttest increased by almost three questions (mean score difference = 2.67), while the difference in the mean score from posttest to delayed posttest decreased by less than one question (mean score difference = 0.89), and the difference in the mean score from pretest to delayed posttest increased by close to two questions (mean score difference = 1.78) (Table 14).

Table 14

<i>Descriptive Statistics by Time (Within Factor)</i>			
	<u>Domain Specific Content Knowledge</u>		
	<u>N</u>	<u>M</u>	<u>SD</u>
Pretest	245	5.51	2.50
Posttest	245	8.18	3.21
Delayed Posttest	245	7.29	3.42

Figure 7 represents the mean score for all condition on the content knowledge instrument for the pretest, posttest, and delayed posttest.



*Figure 18.* Mean score for within factor—time. This graph shows the mean scores for pretest, posttest, and delayed posttest for all condition.

Table 15 presents the descriptive statistics by condition for the results of the pretest, posttest, and delayed posttest of the content knowledge instrument by between factors: control condition ( $SE_{(w/o)}$ ,  $FWE_{(w/o)}$ ), self-explanation condition ( $SE_{(w)}$ ,  $FWE_{(w/o)}$ ), faded worked examples condition ( $SE_{(w/o)}$ ,  $FWE_{(w)}$ ), and both combined condition ( $SE_{(w)}$ ,  $FWE_{(w)}$ ). Figure 19 compares the mean scores on the content knowledge instrument for the pretest, posttest, and delayed posttest for each condition of the experimental design.

Table 15

*Descriptive Statistics for Each Level of the Between Factors***Pretest****Faded Worked Examples**

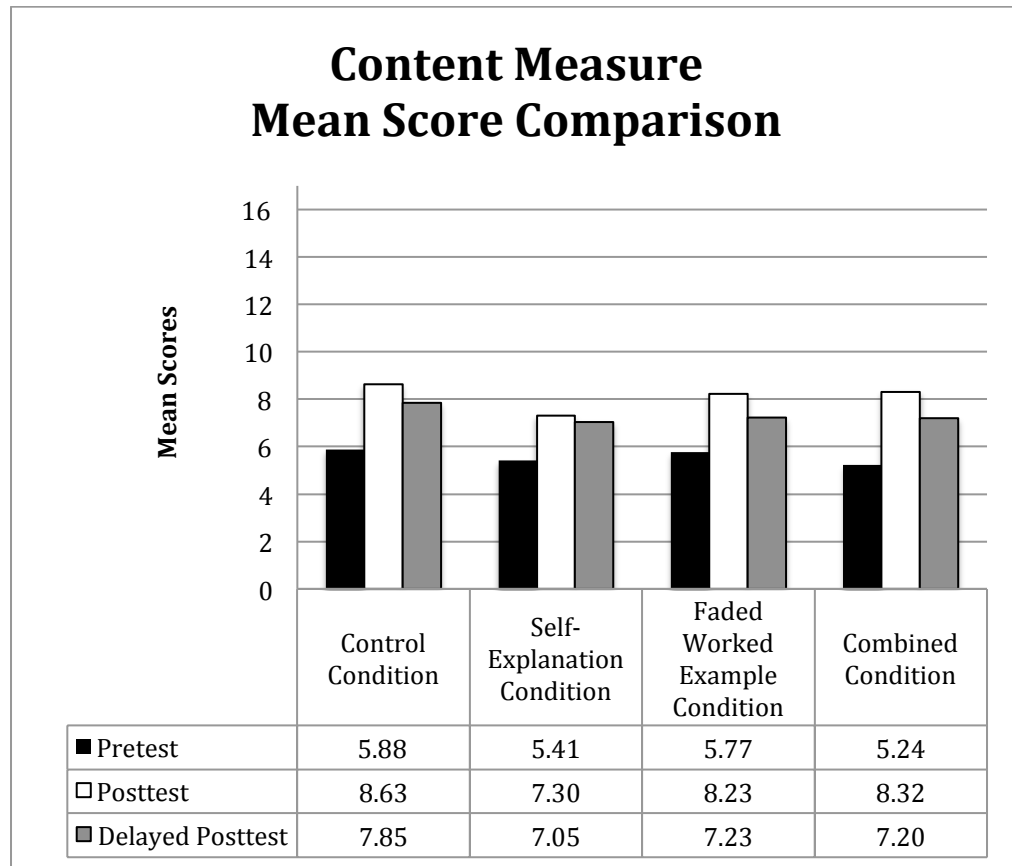
		<b>Without</b>			<b>With</b>		
<b><u>Self-explanation prompt</u></b>	<b>Without</b>	<u>N</u>	<u>M</u>	<u>SD</u>	<u>N</u>	<u>M</u>	<u>SD</u>
		40	5.88	2.28	44	5.41	2.78
	<b>With</b>	<u>N</u>	<u>M</u>	<u>SD</u>	<u>N</u>	<u>M</u>	<u>SD</u>
		61	5.77	2.22	100	5.24	2.61

**Posttest****Faded Worked Examples**

		<b>Without</b>			<b>With</b>		
<b><u>Self-explanation prompt</u></b>	<b>Without</b>	<u>N</u>	<u>M</u>	<u>SD</u>	<u>N</u>	<u>M</u>	<u>SD</u>
		40	8.63	2.97	44	7.30	3.39
	<b>With</b>	<u>N</u>	<u>M</u>	<u>SD</u>	<u>N</u>	<u>M</u>	<u>SD</u>
		61	8.23	2.83	100	8.32	3.41

**Delayed Posttest****Faded Worked Examples**

		<b>Without</b>			<b>With</b>		
<b><u>Self-explanation prompt</u></b>	<b>Without</b>	<u>N</u>	<u>M</u>	<u>SD</u>	<u>N</u>	<u>M</u>	<u>SD</u>
		40	7.85	3.45	44	7.05	3.35
	<b>With</b>	<u>N</u>	<u>M</u>	<u>SD</u>	<u>N</u>	<u>M</u>	<u>SD</u>
		61	7.23	3.64	100	7.20	3.31



*Figure 19.* Mean score for between factors. This figure displays the mean score for the pretest, posttest, and delayed posttest for each of the conditions: control condition ( $SE_{(w/o)}$ ,  $FWE_{(w/o)}$ ), self-explanation condition ( $SE_{(w)}$ ,  $FWE_{(w/o)}$ ), faded worked examples condition ( $SE_{(w/o)}$ ,  $FWE_{(w)}$ ), and both combined condition ( $SE_{(w)}$ ,  $FWE_{(w)}$ ).

## Summary

This study analyzed the effects of two learning strategies, self-explanation prompts and faded worked examples on the science content knowledge of ninth- and tenth-grade biology students at a large, comprehensive, urban high school. The purpose was to advance educational theories related to learner difficulties with understanding scientific inscriptions and the consequences of using argumentation to learn science content. Additionally, the intent of this study was to inform design by determining

whether these instructional strategies, when embedded in the 5-DIE, significantly affected the acquisition and retention of content knowledge.

The research questions were examined through a three factor mixed model ANOVA. Findings for Research Question 1 indicate no significant difference in the acquisition and retention of content knowledge when participants are provided the learning strategy in which self-reflection associated with the meaning and content represented in a scientific inscription was prompted. Findings for Research Question 2 indicate that participants provided with the faded worked example learning strategy scaffolding the development of a scientific knowledge claim resulted in no significant difference in the acquisition and retention of content knowledge. Findings for Research Question 3 show when participants were provided with both scaffolds, self-explanation prompts and faded worked examples; there was still no significant effect in the acquisition and retention of content knowledge.

## **Chapter 5 Discussion**

### **Introduction**

This study evaluated the effect of two learning strategies embedded in a 5-DIE lesson on the acquisition and retention of science content knowledge for ninth- and tenth-grade students enrolled in a biology course at a large, suburban high school in the southwestern United States. The first learning strategy was the use of self-explanation prompts, which were designed to shift learner engagement in the process of learning with inscriptions (e.g., graphs, diagrams, and data) from superficial to meaningful, in order to promote reflective self-explanation related to the science content represented in the inscriptions. The second learning strategy was the use of faded worked examples. This strategy involved a progression of detailed claim statements, in which the processes associated with the development of each component of a scientific claim statement (i.e., claim, evidence, relationship) were made explicit to the learner by modeling the scientific claim statement. This was followed by the systematic removal of the claim statement components as the learner proceeded in developing the skill of writing a scientific claim statement.

A three factor mixed model ANOVA design was used to address three of the research questions explored in this study. Content knowledge, represented by the participants' scores on a 17-item multiple-choice instrument, served as the dependent variable. To address the fourth research question, a comparison of the results of the first three research questions and the related literature informed the identification of factors that could further develop the 5-DIE framework. In the following sections, an overview



of the study and the 5-DIE design framework will be presented and the results and implications related to each of the four research questions will be discussed.

### **Study Overview**

The school context for this study was a large, suburban high school in the southwestern United States. Participants were enrolled in four Biology Honors, eleven General Biology, and three Inclusionary Biology classes taught by four different teachers. Data collection occurred in three phases. The first phase consisted of participants completing the content knowledge pretest instrument. In the experimental phase, the participants, who were grouped by classroom teacher, completed one of the four 5-DIE lessons: (1) with neither self-explanation prompts nor faded worked examples learning strategies (the control condition), (2) with the self-explanation prompts learning strategy, (3) with the faded worked examples learning strategy, or (4) with both self-explanation prompts and faded worked examples learning strategies. A total of 245 students consented/assented to participate in this quasi-experimental study. The first independent variable, self-explanation prompts, was defined by whether a scientific inscription paired with reflective self-explanation prompts was included in Feature 2 of the 5-DIE lesson; the second independent variable, learning strategy two, was defined by whether the faded worked example learning strategy for the evaluation and development of scientific knowledge claims was included Feature 3 of the 5-DIE lesson; and the within factor was time (pre-test to post-test to delayed post-test).

### **Discussion: Research Questions 1-3**

Previous empirical research indicates that learners struggle to understand and interpret scientific inscriptions (e.g., Bowen & Roth, 2002) and that they struggle to learn

science content while engaging in scientific argumentation (e.g., Cross *et al.*, 2008; Ruiz-Primo *et al.*, 2002). The existing literature suggests that the guidance provided by self-explanation prompts and faded worked examples may reduce the extraneous cognitive load associated with unguided activities, thereby shifting the intended content learning towards germane load or the cognitive processing necessary for learning (Kirschner *et al.*, 2006). The expectation for scaffolding learner engagement with self-explanation prompts and faded worked examples was to (a) shift cognitive load from extraneous to germane and (b) make explicit the science concepts, thus leading to a change in focus to emphasize the science content, resulting in the meaningful acquisition and retention of content knowledge. Therefore, based on the existing literature, learning with self-explanation prompts and faded worked examples during the 5-DIE lesson should have supported the acquisition and retention of content knowledge. However, the statistical results from this study indicated that the hypothesized outcomes were not achieved. Although there was an overall gain in the acquisition and retention of domain-specific content knowledge across all conditions (Figure 8), indicating that all learning environments were successful, there were no statistically significant differences between the condition without additional learning strategies and the experimental conditions (i.e., self-explanation, faded worked example, and combined).

The absence of a statistically detectable difference may be attributed to several factors. The materials for all conditions were built using design principles for scaffolding learner engagement in a cyberlearning environment (Linn *et al.*, 2004). Specifically, all conditions—including the control—had some form of prompting: general and/or explicit. An argument will be presented that three factors may have contributed to these results.

First, the 5-DIE lesson representing the control condition was an effective lesson without the additional learning strategies. Second, although the learning strategies were designed to focus learners' cognitive processing on the science content represented in scientific inscriptions and in the claim statements, the self-explanation prompts and faded worked examples may have shifted the self-regulatory skills of self-explanation and the skill of argumentation from extraneous to germane cognitive load instead of shifting the science content to germane cognitive load. Third, the empirical research associated with self-explanation prompts and faded worked examples do not appear to generalize to the target population in the current study.

**Effectiveness of 5-DIE control condition.** The 5-DIE design framework is infused with general prompts – activity, self-monitoring, and self-explanation – and all conditions in the current study, including the control condition, contained each of these prompts as part of the 5-DIE lessons implemented in this study. The self-explanation condition contained both general self-explanation prompts and explicit self-explanation prompts related to the scientific inscriptions. The faded worked example condition contained both faded worked examples and general activity prompts designed to facilitate the development of a claim statement. The combined condition contained the self-explanation and faded worked example learning strategies as well as the general prompts. The condition without the additional self-explanation prompts for scientific inscriptions or faded worked examples for argumentations contained only the general prompts.

The participants assigned to the control condition performed as well as the participants assigned to the experimental conditions. Hence, the equivalent outcomes of the current study may provide evidence that learning with lessons developed in the 5-DIE

design framework containing general prompts is not enhanced by the addition of self-explanation prompts or faded worked examples. This conclusion aligns with the findings of van der Meij and de Jong (2011), who reported a weak effect ( $\eta^2 = 0.025$ ) for high school physics students in an experimental session when comparing general prompts to specific prompts. In addition, the findings of Schwonke *et al.* (2009), with 8th grade students in a 90-minute experimental session, indicated no effect ( $\eta^2 = 0.002$ ) when comparing an established cognitive tutor to the cognitive tutor enhanced with faded worked examples.

van der Meij and de Jong (2011) and Schwonke *et al.* (2009) concluded that there was no increase in content knowledge upon addition of the extra learning strategies because the control learning environments were sufficiently effective. Similarly, the fact that content knowledge did not increase upon the addition of self-explanation prompts and faded worked example learning strategies in the current study may suggest that the control learning environment was sufficiently effective. Since 5-DIE is founded on existing research about learning, this is a reasonable conclusion; however, it is one that must be confirmed by future research.

Two additional explanations will be proposed as to why the participants' content learning was not enhanced by the addition of the learning strategies to 5-DIE lesson: (1) the learning strategies prompted the participants to learn the skills of self-explanation and argumentation rather than the science content as was predicted and (2) the literature supporting the design decisions associated with self-explanation and faded worked examples was not generalizable to 9<sup>th</sup> and 10<sup>th</sup> grade high school students.

## **Cognitive Load & Expertise Reversal Effect**

The learning strategies were meant to shift the science content from extraneous to germane cognitive load with the intent of increasing the acquisition and retention of content knowledge, yet the equivalent outcomes for content knowledge among all interventions indicates the additional learning strategies did not have the intended effect. A potential explanation for this outcome is that the self-explanation prompts and faded worked example learning strategies shifted the self-regulatory skills of self-explanation and the skill of argumentation from extraneous to germane cognitive load instead of shifting the science content to germane cognitive load. The results of the current study indicated that while participants did not perform better with self-explanation prompts and faded worked examples, they also did not perform worse on the assessment of content knowledge. This suggests that the expertise reversal effect was not an issue. In other words, scaffolding engagement multiple times with general prompts as well as explicit self-explanation prompts and faded worked examples did not result in a level of redundancy that adversely affected the participants' acquisition and retention of content knowledge. The conclusion that the additional learning strategies did not result in the expertise reversal effect is supported by the no significant difference results among conditions as well as the equivalent acquisition and retention of content knowledge when the experimental conditions (e.g., self-explanation and faded worked examples) were compared to the control condition.

The equal performance for all conditions may be the result of the general prompts present in all conditions, which shifted the participants' focus towards content learning and the self-explanation prompts and faded worked examples, which directed the

participants' focus to skills related to self-explanation and argumentation. Collectively, these may have reduced any redundant information taxing the working memory. As participants gain proficiency with self-explanation, there may be an improvement in the acquisition and retention of content knowledge. Additional research would be necessary to confirm this conjecture. The results of the current study do suggest that having general prompts alongside self-explanation prompts and faded worked examples with no significant difference in content knowledge acquisition indicates that metacognitive skills related to self-explanation and argumentation may be taught alongside science content with no adverse effect on the acquisition and retention of content knowledge.

### **Generalizability of Support Literature**

The pragmatic nature of Design-Based Research (DBR) indicates, “the value of theory is appraised by the extent to which principles inform and improve practice” (Wang & Hannafin, 2005 p. 7). The practical issues identified for this study in both the development of the 5-DIE design framework as well as in the literature related to science education are the difficulties learners have meaningfully engaging with scientific inscriptions and the disconnect between engaging in argumentation and learning science content (e.g., Bowen & Roth, 2002; von Aufschnaiter *et al.*, 2008). The design decisions associated with addressing these difficulties were also informed by science education literature (Clark, Kirschner, & Sweller, 2012; van Gog & Rummel, 2010). Further, the contextual nature of DBR calls for the results of a study to be connected with both the design process through which results were generated and the setting where the research was conducted (Wang & Hannafin, 2005).

The foundational empirical studies that were used to inform the design of the self-explanation and faded worked example strategies for this study were conducted with an older population of participants (i.e., college undergraduates and financial service employees), which may exhibit key differences when compared to the participants in this study, (Crippen & Earl, 2007; Berthold *et al.*, 2004; Kissane *et al.*, 2008; Renkl *et al.*, 2004). Crippen and Earl's (2007) study, which demonstrated a weak effect ( $\eta^2 = 0.08$ ), was conducted with introductory college chemistry students, all of whom were science majors. The study by Berthold and colleagues (2004) that demonstrated a large effect ( $\eta^2 = 0.89$ ) involved undergraduate psychology students. The participants in the study by Kissane *et al.* (2008) were financial services employees, all of whom were adult learners ( $\eta^2 = 0.18$ ); and in the study by Renkl *et al.* (2004), conducted under strict experimental conditions, participants were undergraduate psychology students ( $\eta^2 = 0.15$ ). All of these participant groups can be identified as highly selected populations (i.e., adult learners in the work force and college students from a select university) (Mayer, Hegarty, Mayer, & Cambel, 2005). The age of the participants in the studies informing the design of this study as well as their acceptance to and attendance at a university or financial service training is not equivalent to the high school science students who were participants in the current study. Therefore, generalizing these results to participants who are fourteen to fifteen years of age in the naturalistic, chaotic setting of a state-mandated biology course may be inappropriate.

**Significance of this study.** Despite the fact that this study did not result in a significant effect, the results are still meaningful. The results of this study are relevant to K-12 science education, as learning in the K-12 context often involves variables that are

not measurable or predictable with general populations (i.e., not highly selected). The hectic, real-life setting of a K-12 classroom is where most science learning occurs (Barab & Squire, 2004). The diversity of the student population sitting in a single classroom includes students with a variety of disabilities (i.e., specific learning disabilities in math and reading, emotional disorders, and health impairments), second language learners, various experience levels in terms of content and self-regulation, and a variety of prior knowledge. These variables can be measured and can inform teaching practices.

Variables such as the hunger level, family support, homelessness, and financial issues are examples of variable that may not be measureable in terms of preparing for teaching.

Furthermore, the unpredictable nature of the K-12 context includes network-computing issues, fire drills, fights among the students, absenteeism, and transience, all of which interrupt the flow of the instruction and in turn affect learning. The learners in K-12 education are a younger and a more generalized population of learners when compared to the college and adult learners represented in the research literature. The significance of this study emphasizes the need for extensive research within the context of K-12 science learning environments. The conclusions drawn from research with undergraduates and adult learners do not necessarily apply to elementary and secondary learners.

### **Implication for the Innovation of 5-DIE**

Research Question 4 was, “How can the results of this study contribute to the further innovation of 5-DIE?” The 5-DIE design framework was developed as a response to the need for an online, inquiry-based, science-learning environment designed to promote critical thinking, problem solving, and scientific literacy. The results of this study can be used to inform the further design and development of the 5-DIE design



framework for cyberlearning environments, because the study evaluated the effectiveness of embedding robust and well-supported learning strategies into the 5-DIE design framework in an attempt to enhance participants' acquisition and retention of content knowledge.

A long-term goal for the research and development of the 5-DIE design framework is to provide educators with a mechanism for developing research-based cyberlearning lessons. The results of this study suggest that the use of general prompts, self-explanation prompts to scaffold learner engagement with scientific inscriptions, and faded worked examples as a learning strategy for the development and evaluation of a scientific claim statement did not influence acquisition and retention of science content in a positive (i.e., learning) or negative (i.e., expertise reversal effect) way. This is evidenced by the overall gain in the acquisition and retention of content knowledge (Figure 8) for all conditions, even though there were no statistical differences among the conditions. However, adding the learning strategies to the lesson lengthens the lesson unnecessarily and the results of this study indicate that there is no additional benefit in the form of learning the content through the addition of the learning strategies.

Design-Based Research requires an “iterative cycle of analysis, design, implementation, and redesign” (Wang & Hannafin, 2005 p. 8). Wang and Hannafin (2005) describe a design framework as a prescriptive and systemic set of guidelines and comprehensive solutions designed to achieve an array of learning outcomes in a learning environment. With the long-term goal of teachers creating lessons in 5-DIE, it is important to recognize that developing self-explanation prompts and faded worked examples is time consuming and requires the lesson developer to have an understanding

of when, where, and how to use these scaffolds in a lesson. 5-DIE is a design framework for cyberlearning environments; therefore, when teachers develop a lesson as a 5-DIE they are encouraged to use specific types of prompts in each of the features. The inclusion of the general prompts, the self-explanation prompts, and the faded worked examples in the design framework means teachers designing lesson in 5-DIE do not have to have advanced understanding of the scaffolds and learning strategies. Based on the results of the current study, the argument can be made that an educator's time spent developing lessons would be better spent building within the 5-DIE design framework.

### **Implications for Science Education**

The results of this study have important implications for science education and may provide valuable insight for researchers and teachers on the effectiveness of using self-explanation prompts and faded worked examples to engage high school students in the learning of science content. Three implications emerged from this study. First, general prompts, when compared to specific prompts for self-explanation and faded worked examples, are as effective at scaffolding learning. Second, the addition of self-explanation prompts paired with scientific inscription and faded worked examples for the development of scientific claim statements may result in the concurrent learning of content, self-regulatory skills, and argumentation. Finally, there is a need for more research in the context of K-12 classrooms evaluating the effect of theory-based practices developed using college and adult learners under controlled experimental conditions.

**Effectiveness of general prompts.** The findings of this study are consistent with those of Schwonke *et al.* (2009) and van der Meij and de Jong (2011) in that, when designing lessons where the central focus is learning science content, it is as effective to

use general prompts as it is to use self-explanation prompts, faded worked examples, or both. This is important for science education. The development of learning strategies like self-explanation prompts and faded worked examples is time consuming. Furthermore, the additional learning strategies unnecessarily increase the length of the lesson. Therefore this study suggests that general prompts should be used rather than the specific prompts when designing a lesson using the 5-DIE design framework.

With this conclusion in mind, continued research on 5-DIE is necessary. 5-DIE provides strategies, such as general prompts, that appear to help learners achieve an array of learning outcomes in a cyberlearning environment. However, in order to make this inference, an effect size for a 5-DIE lesson pitted against a variety of lessons on the same concepts needs to be determined. Currently, there are no baseline statistics for the effect of the 5-DIE design framework that can be used to evaluate participant performance against other instructional approaches. A baseline would provide a criterion to compare all research results for future 5-DIE design innovations.

**Generalizability.** Barab and Squire (2004) emphasize that the learning context is a core part of educational research and “not an extraneous variable to be trivialized” (p. 3). The current study highlights the need to better understand how theory developed outside the context of K-12 science cyberlearning environments can be appropriately applied to K-12 learners. As evidenced by this study and the assertions of Barab and Squire (2004) that learning, cognition, knowing, and context cannot be treated in isolation, considerations must be made for the tremendous differences in variables such as prior knowledge, self-regulatory skills, and motivation that exist between the college and pre-college learners when making K-12 curriculum design decisions. Given these

differences, more research specific to the context of K-12 curriculum design decisions is needed.

### **Limitations of Study**

All studies have limitations to the internal validity, generalizability, and applicability of their results. This study has several limitations. Due to the quasi-experimental design of this study, participants were not randomly assigned to the treatment and control groups. This increases the risk that there may have been pre-existing differences between participants in the inclusion biology, general biology, and honors biology related to test-taking variables such as reading level, test anxiety, and variation in testing conditions. This is the nature of the classroom environment.

Participants may not have been randomly assigned, but teachers cannot choose their students. This study may better reflect the nature of the classroom environment. Though this may be a limitation, the experimental design helped to mitigate the effects by assigning approximately equal number of participants enrolled in to each biology course (e.g., inclusionary biology, general biology, and honors biology) to each condition.

The naturalistic setting of a state-mandated ninth- and tenth-grade biology course at a large, suburban high school in the southwestern United States provided the opportunity for this study to have a large and diverse sample population. During this study several disruptions to the learning environment occurred, such as network computing at the school and district level failing several times, a fire drill, and a threat of violence against the students, which resulted in high number of absences on the day of the posttest. Each of the events may have influenced the outcome of this study and are typical to what Barab and Squire (2004) describe as, “the buzzing, blooming confusion of

real-life settings where most learning actually occurs” (p. 4). However, the results of this study are not generalizable beyond the context of the learning environments of the 5-DIE lessons implemented. The applicability of the results is limited to design decisions related to the research and design of the 5-DIE design framework.

The content knowledge measure was specifically designed to prevent a ceiling effect, meaning questions were designed with the participants with the highest efficacy in the content and test-taking in mind. The participant pool consisted primarily of inclusionary and general biology participants (77.5%). The inclusionary and general biology participants included participants with documented disabilities (i.e., specific learning disabilities in math and reading, emotional disorders, and health impairments) and English language learners. This may have contributed to poor test performance due to low reading levels, test anxiety, and item difficulty. There is also the possibility that participants became familiar with content knowledge measure and remembered responses for later testing. While every effort was made to make testing conditions as comparable as possible for the three administrations of the test in which four different teachers proctored, there is the potential for variation in the testing condition.

### **Suggestions for Further Research**

The cyclic nature of design-based research logically leads to more questions to explore with the intent of the continued research and development of the 5-DIE design framework (Barab & Squire, 2004; Edelson, 2002; Wang & Hannafin, 2005). Future work will include determining the effectness of 5-DIE and evaluating the effect of pairing self-explanation prompts with faded worked examples on the acquisition and efficiency of learning content knowledge.

Previous research (Kern *et al.*, in press) provides evidence for the fidelity and usability of the 5-DIE design framework in the naturalistic setting of high school science classroom. The next step for potentially improving the design framework is to determine an initial effect size. Research of this nature will move beyond the question of whether 5-DIE works to addressing how well 5-DIE works in a specific context. This study established that there was no effect for the self-explanation condition ( $\eta^2 = 0.009$ ), faded worked example condition ( $\eta^2 = 0.001$ ), and self-explanation and faded worked example condition ( $\eta^2 = 0.004$ ). Determining the effect size is an important statistical tool for interpreting the usefulness of the 5-DIE design framework and should be included in future research. Once an effect size has been determined, then additional research associated with the learning strategy from this study as well others may be explored. The overall effect of using 5-DIE as an design framework may be determined by comparing it to a variety of lessons using a variety of pedagogies, but with the same concept. Currently, there are no baseline statistics for the effect of the 5-DIE design framework that can be used to evaluate participant performance against other instructional approaches. This baseline would provide a criterion to compare all research results for future 5-DIE design innovations.

In this study the faded worked examples were presented with an explanation for each of the claim statement components. There was no prompting for the participants to self-explain the components or the content represented in the worked examples. Crippen and Earl (2007) indicated that pairing self-explanation prompts with the faded worked examples resulted in a more effective learning strategy than self-explanation prompts or faded worked examples alone. Therefore, determining the effect of faded worked

examples when paired with self-explanation prompts for the evaluation and development of scientific knowledge claims during a 5-DIE lesson on the acquisition and retention of domain-specific content knowledge would contribute to the continued research and development of the 5-DIE design framework (i.e., self-explanation prompts paired with the faded worked examples).

Furthermore, Schwonke *et al.* (2009) and Renkl *et al.* (2004) concluded that learning with faded worked examples required less time to learn a problem solution. Determining the effect the embedded 5-DIE scaffolds and faded worked examples have on learning efficiency in terms of the required learning time would contribute to the continued research and development of the 5-DIE design framework.

### **Concluding Remarks**

The purpose of this study was to advance educational theories related to difficulties learners have with understanding and using scientific inscriptions and argumentation to learn science content. In addition, the intent was to determine whether the self-explanation prompts and faded worked examples learning strategies significantly affected the acquisition and retention of content knowledge and to inform design decisions associated with 5-DIE. From the perspective of the design based research paradigm, the research process is meant to address educational needs by first making research-based conjectures that are explored through the design, implementation, and evaluation of an intervention, with the results informing theory, future innovations, and the researcher's understanding associated with teaching and learning (Edelson, 2002; Wang & Hannafin, 2005)

This entire process was meant to address two educational needs related to learner difficulties with learning content when engaging with scientific inscriptions and in argumentation. First, research-based conjectures were made that self-explanation prompts and faded worked examples would shift science content represented in inscriptions and scientific knowledge claims from extraneous to germane load. Second, these conjectures were explored through the design, implementation, and evaluation of lesson created in the 5-DIE design framework. The outcomes of this study informed theory related to the use of general and explicit prompts with high school learners. The findings revealed a need for more research evaluating how theory developed outside the naturalistic context of a K-12 science classroom effects the acquisition and retention of content knowledge of K-12 science learners. Furthermore, the findings from this study may inform innovations of 5-DIE, contributing to the robust, theory-based nature of the design framework through future research endeavors related to understanding the effects of general prompts, self-explanation prompts, and faded worked examples on content knowledge acquisition as well as skills in self-explanation and argumentation in a cyberlearning environment.

The research and development of 5-DIE comes as a response to the need for an inquiry-based cyberlearning environment meant to promote critical thinking, problem solving, and scientific literacy. The time and effort allocated to the design and development of the self-explanation prompts and faded worked examples for a lesson may not be necessary when the 5-DIE approach is employed because it already includes a rich variety of scaffolds. 5-DIE provides guidelines and comprehensive solutions designed to achieve a range of goals in cyberlearning environments; therefore, designing

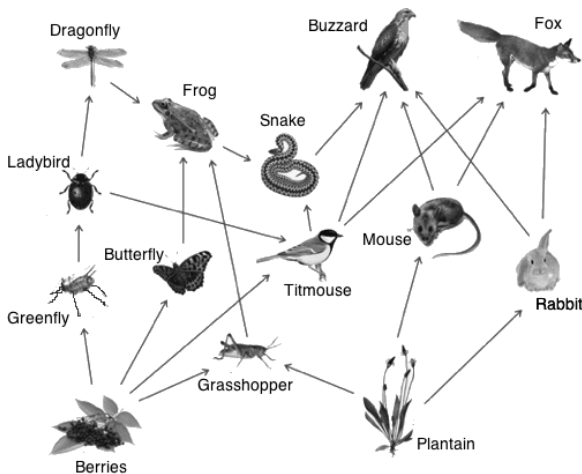


a lesson in 5-DIE may be more efficient than and as effective as individually developing self-explanation prompts or faded worked examples for a science lesson.

Finally, the design based research process is meant to inform the researcher's understanding associated with teaching and learning. The decisions made by teachers in K-12 education are informed by theories that may not be generalizable to their context. This study emphasizes the disconnect between research with the highly self-regulated world of college learners and the more generalized population of K-12 learners. Yet the theories developed with college students as participants influence teaching practices for the K-12 learner. This research, as well as future research endeavors catalyzed by this study, is and should be centered on the naturalistic and often times chaotic context of the K-12 science classroom where countless variables influence the learning. This study has brought to the forefront the need for research where K-12 learning occurs – in the K-12 classroom.

## APPENDIX A: CONTENT KNOWLEDGE INSTRUMENT

1. Seeing a mountain lion is an exciting and rare event, because there are so few of them. How is it that there are fewer predators, like mountain lions, than their prey, like deer?
  - a. Because energy at each trophic level in a food web is lost to the environment, each mountain lion has to eat many deer to survive.
  - b. There are as many mountain lions as there are deer, but they are very shy and people are not their natural prey, so we don't see them very often.
  - c. Mountain lions are the exception among animals; other top predators (e.g. eagles and hawks) are about as common as their prey.
  - d. Top predators like mountain lions need a lot of energy and they spend huge amounts of energy hunting, and often starve to death.
2. When one organism eats another, not all of the chemical energy stored in the food gets transferred to the consumer. What happens to the energy "lost" during each energy transfer?
  - a. all of the energy is passed on to the next trophic level
  - b. most of the energy is passed on to the next trophic level
  - c. most of the energy is passed on to the next trophic level, but some is transferred to the environment
  - d. a small percentage of the energy is passed on and most is transferred to the environment



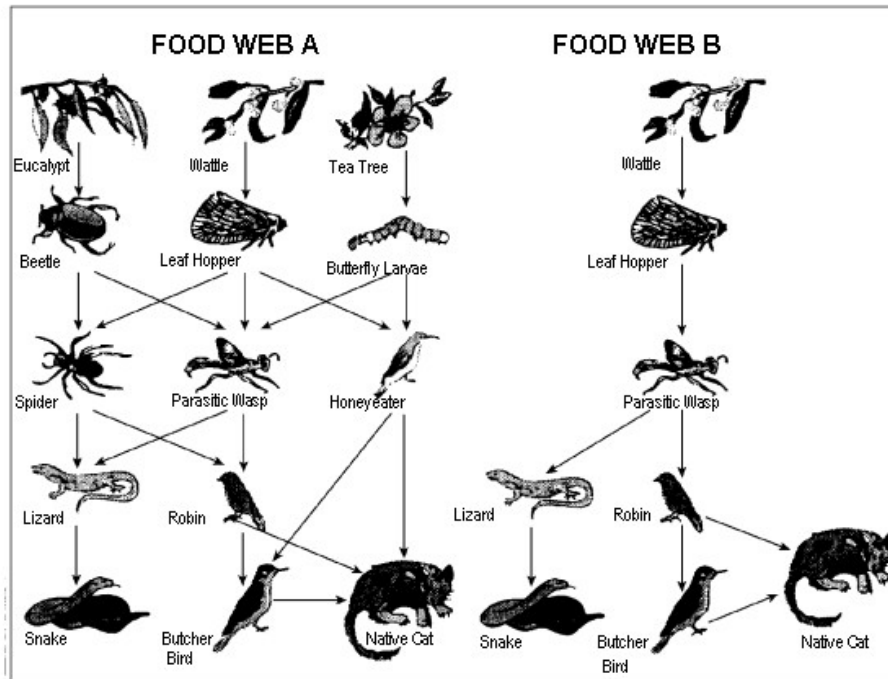
3. Using the food web above, what might be the first effects on the number of organisms in the lower two trophic levels if we removed a tertiary consumer (buzzard)?
  - I. The number of producers and primary consumers would stabilize.
  - II. The number of producers would decrease.
  - III. The number of primary consumers would increase.

- IV. The number of foxes would increase.
- V. The number of number of primary consumers and secondary consumers would stabilize.

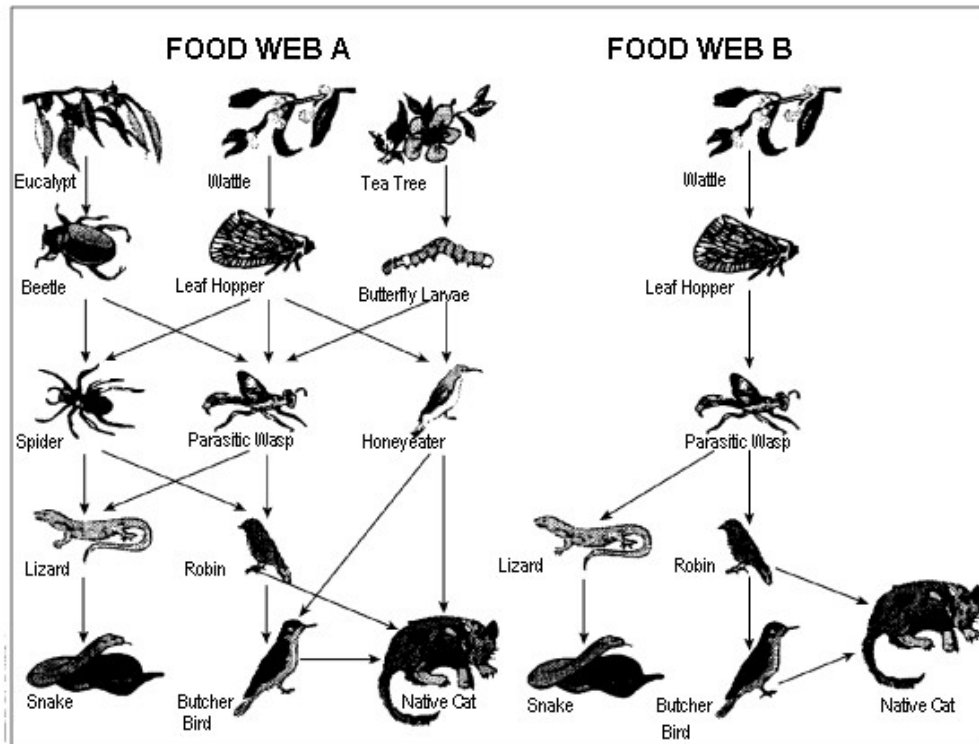
Using the statements above, identify the scenario that best describes the impact of eliminating a top predator.

- a.  $II \rightarrow III \rightarrow V \rightarrow IV \rightarrow I$
  - b.  $III \rightarrow II \rightarrow IV \rightarrow V \rightarrow I$
  - c.  $IV \rightarrow I \rightarrow III \rightarrow V \rightarrow II$
  - d.  $III \rightarrow II \rightarrow I \rightarrow IV \rightarrow V$
4. Which of the following statements is true?
- a. Carbon emissions from cars in Nevada can impact the birth rate of sea urchins in nearshore ecosystems in the Pacific Ocean.
  - b. Food like perch is an unlimited food source for humans.
  - c. An increase in ocean temperatures will increase the amount of producers like kelp and phytoplankton.
  - d. A decrease in ducks in the nearshore environment will increase the competition sea otters have for food.
5. Which of the following depicts the flow of energy in an ecosystem?
- a.  $\text{sun} \rightarrow \text{decomposers} \rightarrow \text{producers} \rightarrow \text{consumers}$
  - b.  $\text{decomposers} \rightarrow \text{producers} \rightarrow \text{consumers}$
  - c.  $\text{sun} \rightarrow \text{producers} \rightarrow \text{decomposers} \rightarrow \text{consumers}$
  - d.  $\text{sun} \rightarrow \text{producers} \rightarrow \text{consumers} \rightarrow \text{decomposers}$
6. About what percent of the sun's energy that a plant (producer) absorbs is transferred to a primary consumer like a rabbit?
- a) 90-100%
  - b) 60-70%
  - c) 30-40%
  - d) 10-20%
7. When humans make decisions about what to eat and what materials to use when building their homes, consider how their decisions may
- a. impact the local environment.
  - b. impact environments that are not local.
  - c. change how organisms interact with each other and their environment.
  - d. all of the above

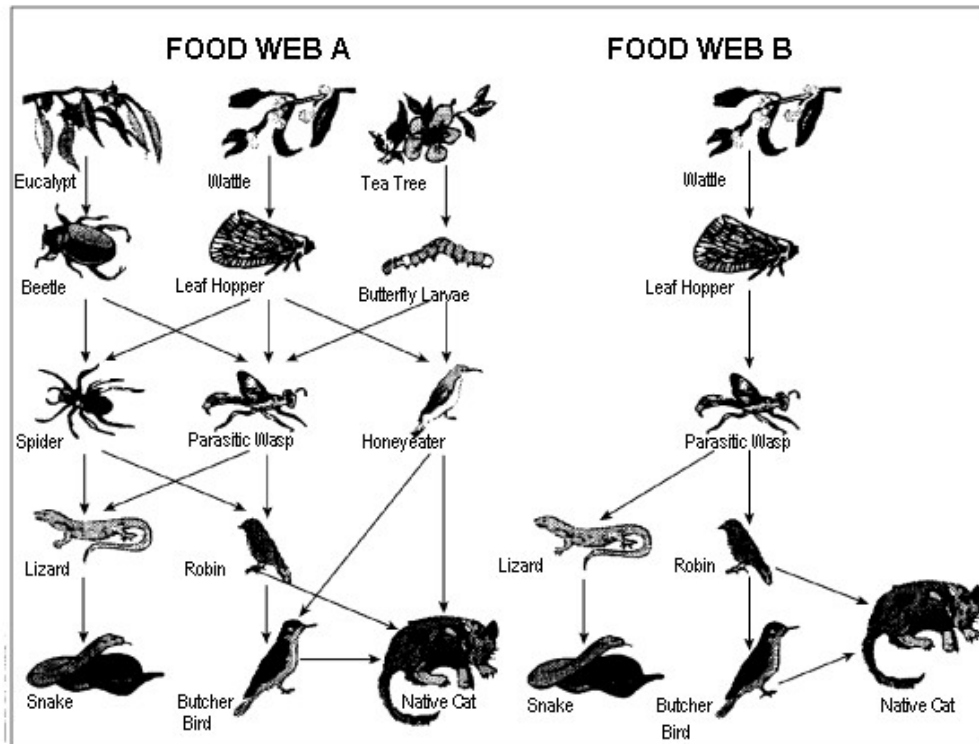
The diagrams below are food webs for an Australian ecosystem. Use this diagram to answer questions 8-9.



8. Look at **Food Web A**. Which animals have three direct sources of energy?
  - a. Butcher Bird and Robin
  - b. Leaf Hopper and Parastic Wasp
  - c. Parastic Wasp and Native Cat
  - d. Native Cat and Leaf Hopper
  
9. Which of the following explains your choice to question #8?
  - a. Food webs use arrows to represent feeding interactions among selected populations of organisms. (1)
  - b. Food webs use arrows to represent energy transfer among selected populations of organisms. (2)
  - c. Food webs use arrows to represent who eats whom among selected populations of organisms. (0)
  - d. Food webs use arrows to represent competition for food among selected populations of organisms. (0)



10. Food web A and food web B are found in different locations. If the Leaf Hopper was exposed to a pesticide that kill off the insect population in both locations, which of the following statements is the best claim statement for the effect this would have on the food webs?
- The effect would be greater in food **web A** because the Parasitic Wasp has only one food source in web A.
  - The effect would be greater in food **web B** because the Parasitic Wasp has only one food source in web B.
  - The effect would be greater in food **web A** because the Parasitic Wasp has several food sources in web A.
  - The effect would be greater in food web B because the Parasitic Wasp has several food sources in web B.



Source: Adapted from Steve Malcolm: 'Biodiversity is the key to managing environment', *The Age*, 16 August 1994.

11. Look at **Food Web A**. If the Leaf Hopper was exposed to a pesticide that kill off the insect population in both locations, which of the following statements is the best prediction for the effect this may have on the beetles and butterfly larvae in food web A? The number of beetles and butterfly larvae would...

- decrease over time because their predators have one less energy source.
- decrease over time because the beetles and butterfly larvae have more competition for their energy source.
- increase over time because they have one more energy source.
- increase over time because the beetles and butterfly larvae have less competition for their energy source.

12. Use the food chain below to answer the next question.

Grass → Prairie dog → Rattlesnake → Hawk

What sequence below best represents estimated percent of energy passed from one organism to the next in the food chain above?

- 100% → 10% → 1% → 0.1%
- 100% → 50% → 25% → 12.5%
- 100% → 75% → 50% → 25%
- 100% → 90% → 80% → 70%

13. Which of the following explains your choice to question #12?
- a. Energy is transferred to the environment. (1)
  - b. Approximately 80% - 90% of the energy consumed by an organism is used to live and therefore transferred to the environment. (2)
  - c. Most of the energy in a food chain is passed from one organism to the next.
  - d. Only about 10% of the energy consumed by an organism is used to live and therefore most is transferred to the next trophic level.

14. Use the description below to answer the following question.

*In a marine ecosystem, a disease killed most of the sea otters. As a result, the number of sea urchins and clams increased, which caused the sea gull population to increase, and the seaweed population to decrease.*

Which of the following explains the increase in the sea gull population?

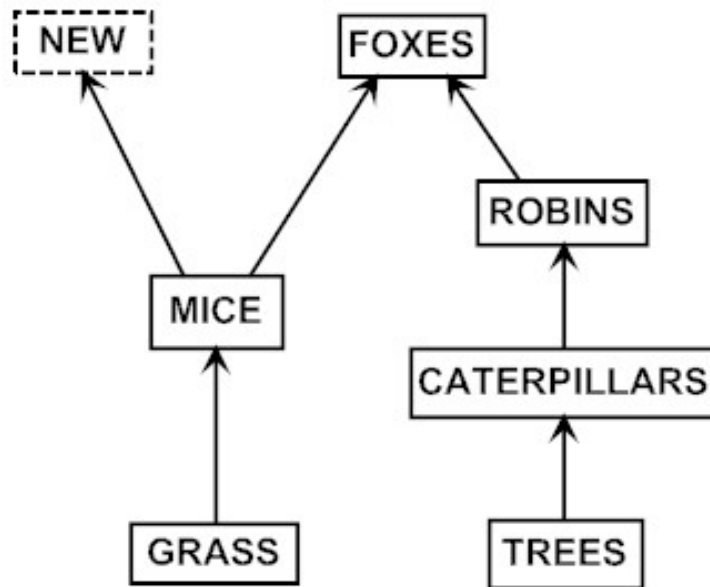
- a. If sea gulls eat seaweed, with the decrease in seaweed there is a *lower* amount of energy available for the sea gulls.
  - b. If sea gulls and otters eat clams, with the otters gone there is a *greater* amount of energy available for the sea gulls.
  - c. If sea gulls eat seaweed, with the decrease in seaweed there is a *greater* amount of energy available for the sea gulls.
  - d. If sea gulls and otters eat clams, with the otters gone there is a *lower* amount of energy available for the sea gulls.
15. The diagram below represents the feeding relationships between populations of organisms in an area.



Using only the relationships between the organisms shown in the diagram, if most of the worms are killed, which of the following statements describes what will happen to the number of robins and why?

- a. The number of robins will increase because there are fewer worms to eat them.
- b. The number of robins will decrease because there are not enough worms for them to eat.
- c. The number of robins will stay the same because the worms are killed, not the robins.
- d. The number of robins will stay the same because a change in the population of worms will not affect any other population of organisms.

16. The diagram below represents the feeding relationships between populations of plants and animals in an area. The arrows point from the organisms being eaten to the organisms that eats them.



A new species that eats only mice becomes part of this food web, greatly reducing the number of mice in this area. Using only the relationships between the plants and animals shown in the diagram, what effect would the new species have on the caterpillar population if the number of foxes stays the same?

- a. The number of caterpillars would increase.
  - b. The number of caterpillars would decrease.
  - c. The number of caterpillars would stay the same.
  - d. There is not enough information to tell what would happen to the number of caterpillars.
17. Which of the following explains your choice to question #16?
- a. Changes in a food web have little or no effect on other organisms that are not directly connected in the food web.
  - b. Changing the number of organisms will not affect the organisms that are one or more connection away from the change.
  - c. Changes in a food web may affect organisms that are not directly connected by a feeding relationship even if they are several connections away in a food web. (2)
  - d. Changing the number of organisms can affect the organisms that are one or more connection away from the change. (1)
  - e. If the size of one population in a food web is changed, all other populations in the web will be changed in the same way.



## APPENDIX B: UNLV IRB APPROVAL



### Social/Behavioral IRB – Expedited Review Approval Notice

#### NOTICE TO ALL RESEARCHERS:

*Please be aware that a protocol violation (e.g., failure to submit a modification for any change) of an IRB approved protocol may result in mandatory remedial education, additional audits, re-consenting subjects, researcher probation, suspension of any research protocol at issue, suspension of additional existing research protocols, invalidation of all research conducted under the research protocol at issue, and further appropriate consequences as determined by the IRB and the Institutional Officer.*

**DATE:** June 21, 2012

**TO:** Dr. P.G. Schrader, Teaching and Learning

**FROM:** Office of Research Integrity - Human Subjects

**RE:** Notification of IRB Action  
Protocol Title: **Determining the impact of scaffolded worked examples on domain-general and domain-specific content knowledge**  
Protocol #: 1205-4142  
Expiration Date: June 20, 2013

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This memorandum is notification that the project referenced above has been reviewed and approved by the UNLV Social/Behavioral Institutional Review Board (IRB) as indicated in Federal regulatory statutes 45 CFR 46 and UNLV Human Research Policies and Procedures.

The protocol is approved for a period of one year and expires June 20, 2013. If the above-referenced project has not been completed by this date you must request renewal by submitting a Continuing Review Request form 30 days before the expiration date.

#### PLEASE NOTE:

Upon approval, the research team is responsible for conducting the research as stated in the protocol most recently reviewed and approved by the IRB, which shall include using the most recently submitted Informed Consent/Assent forms and recruitment materials. The official versions of these forms are indicated by footer which contains approval and expiration dates.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through ORI - Human Subjects. No changes may be made to the existing protocol until modifications have been approved by the IRB. Modified versions of protocol materials must be used upon review and approval. Unanticipated problems, deviations to protocols, and adverse events must be reported to the ORI – HS within 10 days of occurrence.

If you have questions or require any assistance, please contact the Office of Research Integrity - Human Subjects at [IRB@unlv.edu](mailto:IRB@unlv.edu) or call 895-2794.

Office of Research Integrity - Human Subjects  
4505 Maryland Parkway • Box 451047 • Las Vegas, Nevada 89154-1047  
(702) 895-2794 • FAX: (702) 895-0805

## APPENDIX C: CONSENT FORM



### PARENT PERMISSION FORM

Department of Educational Psychology

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**TITLE OF STUDY:** *Determining the impact of impact of scaffolded worked examples on domain-general and domain-specific content knowledge.*

**INVESTIGATOR (S):** Dr. P.G. Schrader (UNLV Professor) and Cindy L. Kern (UNLV Doctorate student and Clark County School District Science Teacher)

**CONTACT PHONE NUMBER:** Dr. P.G. Schrader 702-895-3331

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1. Hi, I'm a teacher at your child's school and a student at the University of Nevada, Las Vegas (UNLV). My name is Cindy Kern, and I would like to use your child's science class assessment data for my doctoral dissertation about student learning outcomes.
2. If you agree, I will receive your child's science class assessment data without their name (or any other identifiable information) from their science teacher.
3. This will help me write my dissertation and may help teachers and students in the future.
4. There are no expected risks to your child by allowing me to use their data.
5. Your choice to either allow or not allow me to use your child's data is completely voluntary and will have no effect on their relationship with their teacher, their school, UNLV, or me.
6. If you have any questions you may contact me: Cindy Kern, or my UNLV faculty advisor: Dr. Schrader at 702-895-3331. For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you may contact the UNLV Office of Research Integrity – Human Subjects at 702-895-2794, toll free at 877-895-2794, or via email at [IRB@unlv.edu](mailto:IRB@unlv.edu)
7. If you agree to allow me to use your child's data, please print their name and print and sign your name. You must be the parent of this child and be 18 years of age or older to sign.

---

Signature of Parent

---

Child's Name (Please print)

---

Parent Name (Please Print)

---

Date

*Approved by the UNLV IRB. Protocol #1205-4142*

*Received: 06-07-12 Approved: 06-21-12 Expiration: 06-20-13*

1 of 1

## APPENDIX D: ASSENT FORM



### ASSENT TO PARTICIPATE IN RESEARCH

***Determining the impact of impact of scaffolded worked examples on domain-general and domain-specific content knowledge.***

1. Hi, I'm a teacher at your school and a student at the University of Nevada, Las Vegas (UNLV). My name is Cindy Kern, and I would like to use your science class assessment data for my doctoral dissertation about student learning outcomes.
2. If you agree, I will receive your science class assessment data without your name (or any other identifiable information) from your science teacher.
3. This will help me write my dissertation and may help teachers and students in the future.
4. There are no expected risks to you by allowing me to use your data.
5. Your choice to either allow or not allow me to use your data is completely voluntary and will have no effect on your relationship with your teacher, your school, UNLV, or me. Choosing to or not to participate in this study will have no effect on your grade.
6. If you have any questions you may contact me: Cindy Kern, or my UNLV faculty advisor: Dr. Schrader at 702-895-3331. For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you may contact the UNLV Office of Research Integrity – Human Subjects at 702-895-2794, toll free at 877-895-2794, or via email at [IRB@unlv.edu](mailto:IRB@unlv.edu)
7. Please talk this over with your parents before you decide whether or not to participate. We will also ask your parents to give their permission for you to take part in this study. But even if your parents say “yes” you can still decide not to do this.
8. Signing your name at the bottom means that you agree to be in this study. You and your parents will be given a copy of this form after you have signed it.

\_\_\_\_\_  
Print your name

\_\_\_\_\_  
Date

\_\_\_\_\_  
Sign your name

***Approved by the UNLV IRB. Protocol #1205-4142  
Received: 06-07-12 Approved: 06-21-12 Expiration:06-20-13***

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International Society for Technology in Education (ISTE)

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CINDY L. KERN

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## Curriculum Vita

### Education

May 2013	University of Nevada, Las Vegas – <i>Ph.D. in Science Education</i> <i>Dissertation: Determining the effect of scaffolded instructional strategies on content knowledge</i>
2007	University of Nevada, Las Vegas – <i>Master of Education</i>
1997	University of Nevada, Las Vegas – <i>B.S. in Secondary Education</i>

### Employment

2009 – Present	University of Nevada, Las Vegas Adjunct Faculty
1997 – Present	Green Valley High School, Clark County School District Science Teacher

### Professional Experience

#### Research Experience

2012 – Present	Online Secondary Science Methods Course <i>Lead researcher for the design, development, &amp; implementation of for an online science methods course.</i>
2009 – 2012	Cyberlearning Climate Change Curriculum Development Research Team <i>Design, Development &amp; Implementation for multiple climate change curricular units.</i>
2009 – 2012	Self Assembly Research Team <i>Analyzed interviews and survey response for several hundred scientist and teachers.</i>
2008 - Present	Nature of Online Science Laboratory Research Team <i>Analyzed survey results</i>
2009 – 2010	Representation of the aspects of nature of science in textbooks <i>Analyzed elementary, middle school, and high school textbooks</i>



## Teaching Experience

2009 – Present	University of Nevada, Las Vegas – Secondary Science Methods
1997 – Present	Biological Science (Biology, Biology Coteach, Biology Honors, Biology II AP/IB)
2006 – Present	Integrated Science (Physics, Chemistry, Geoscience, Biology)

## Curriculum Development

2012	University of Nevada, Las Vegas – Online Secondary Science Methods
2011 – Present	University of Nevada, Las Vegas – Blended Secondary Science Methods
2009 – 2011	University of Nevada, Las Vegas – Secondary Science Methods
2009 – Present	University of Nevada, Las Vegas – Climate Change Cyberlearning Curriculum Development (C4D)
2008 – 2009	University of Nevada, Las Vegas – Department of Defense Education Activity (DoDEA) Virtual Science Curriculum Development
	Lead Developer – Biology
	Collaborative Developer – Earth Science, Chemistry, & Physics

## Professional Development

2012	<i>Venture Into Scientific Inquiry Organized around Nevada Standards</i> (VISIONS) – Elementary Science Content & Pedagogy – Developer
2008 – 2010	<i>Math Integrated w/ Science &amp; Technology</i> (MIST) – Middle School Science & Math Content & Pedagogy – Teacher Leader
2005 – 2008	<i>Proficiency &amp; Success in Science</i> (PASS) – High School Science Content & Pedagogy – Teacher Leader
2009	Implementing Concept Mapping – Developer & Facilitator
2009	Advanced Concept Mapping – Developer & Facilitator
2008	Essential Features of Inquiry – Developer & Facilitator
2008	Self-Regulated Learning – Developer & Facilitator
2008	Mapping for Conceptual Change – Developer & Facilitator

## Professional Service

2012	National Association of Research in Science Teaching – Strand 12 Assessor
2011 – Present	Nevada STEM Education Coalition
2009 – Present	Journal of Science Education and Technology – Springer – Reviewer
2008 – Present	Nevada Department of Education – Science Proficiency Exam Committee
2010 – Present	Nevada Department of Education – Alternative Science Proficiency Exam Committee
2004 – 2011	Clark County School District – High School Science Fellowship (Science Curriculum Revision)
2008	Regional Professional Development Division – Middle School <i>TIPS: Targeted Interventions for Proficiency in Science</i> – Co-Author
2007	Regional Professional Development Division – High School <i>TIPS: Targeted Interventions for Proficiency in Science</i> – Co-Author
2007	Nevada State Math & Science Conference – Co-Chair
2003 – 2007	Mirage Dolphin Habitat – Educational Consultant
2003 – 2007	Clark County School District – Middle School Science Cadre (6 <sup>th</sup> – 8 <sup>th</sup> Grade Science Curriculum Revision)
2006	Clark County School District – Biology Syllabus Revision Committee
2006	Clark County School District – Biology Textbook Adoption Committee
2002	Clark County School District – Marine Science Syllabus Revision Committee
2002	Clark County School District – Marine Science Textbook Adoption Committee
1999	Clark County School District – Biology Syllabus Revision Committee
1999	Clark County School District – Biology Textbook Adoption Committee
1998	Clark County School District – Earth Science Syllabus Revision Committee
1998	Clark County School District – Earth Science Textbook Adoption Committee

## Professional Recognition

2013	National Technology Leadership Initiative (NTLI) Award Finalist
2012	Outstanding Graduate Student Teaching Award - Nominated
2010	iNACOL Important Research by an Individual, Team, or Organization – Recipient
2010	UNLV/MGM Teacher of the Game – Recipient
2009	Recipient, <b>Presidential Award for Excellence in Mathematics and Science Teaching</b> – Recipient
<b>2007 &amp; 2009</b>	<b>Presidential Award for Excellence in Mathematics and Science Teaching</b> – State Finalist

## Research & Scholarship

### Book Chapters

- Crippen, K. J., Archambault, L. M., & Kern, C. (in press). Using Scaffolded Vee Diagrams to Enact Inquiry Based Learning In A. Hirumi (Ed.), *Designing online and hybrid learning environments: A grounded approach to facilitating e-learning*: International Society for Technology in Education (ISTE). (**invited**)
- Ebert, E. K., Crippen, K. J., Kern, C., Reichenbach, R., & Waldman, C. A. (2009). Learning Science with Inquiry in the Clark County School District. In R. E. Yager (Ed.), *Inquiry: The Key to Exemplary Science* (Vol. 6): NSTA Press.

### Peer-Reviewed Journal Articles

- Kern, C. L., Crippen, K. J., & Skaza, H. (in press). The fidelity and usability of 5-DIE: A design study of enacted cyberlearning. *Journal of Computers in Mathematics and Science Teaching*.
- Crippen, K. J., Archambault, L. M., & Kern, C. L. (2013). The nature of laboratory learning experiences in secondary science online. *Research in Science Education*, 43(3), 1029-1050. doi: 10.1007/s11165-012-9301-6
- Kern, C. L., & Crippen, K. J., (2008). Mapping for Conceptual Change. *The Science Teacher*. 75(September), 32-38.

## Research Presentations

### International

- 2013, Kern, C.L. *The Impact of an Online Secondary Science Method Course on Pre-service teachers Efficacy, Beliefs, and Perceptions of Teaching Science*. Paper to be presented at the Association of Science Teacher Education (ASTE) International Conference in Charleston, SC.
- 2012, Kern, C., Crippen, K. J., Skaza, H., Schrader, P. G., Berry, N., & Rollans, J. *The Impact of Blended Cyberlearning about Climate Change on Students and Teachers*. Paper presented at the National Association of Research in Science Teaching (NARST), Indianapolis, IN.
- 2010, Crippen, K. J., Archambault, L. M., & Kern, C. (3/22). *Examining the Use of Laboratory Activities in Secondary Science Online*. Paper presented at the National Association of Research in Science Teaching (NARST) Annual Meeting, Philadelphia, PA.

### National

- 2012, Kern, C., Crippen, K. J., & Archambault, L. M. *Scaffolded Vee Diagram: An Inquiry Environment for Cyberlearning*. Paper presented at the National Science Teachers Association (NSTA), Indianapolis, IN.
- 2012, Orgill, M., Bussey, T., Crippen, K. J., Ho, W., Kern, C., Litster, M., & Wood, S.. *Researchers' perceptions of self-assembly: Capturing a field in scientific revolution*. Paper presented at the 22nd Biennial Conference on Chemical Education (BCCE), State College, PA.
- 2012, Bussey, T., Crippen, K. J., Ho, W., Kern, C., Litster, M., Orgill, M., & Wood, S.. *Researchers' perceptions of self-assembly: Reactions to published definitions of self-assembly*. Paper presented at the 22nd Biennial Conference on Chemical Education (BCCE), State College, PA.
- 2012, Litster, M., Bussey, T., Crippen, K. J., Ho, W., Kern, C., Orgill, M., & Wood, S.. *Researchers' perceptions of self-assembly: Differences between life scientists and chemists*. Paper presented at the 22nd Biennial Conference on Chemical Education (BCCE), State College, PA.
- 2012, Wood, S., Bussey, T., Crippen, K. J., Ho, W., Kern, C., Litster, M., & Orgill, M.. *Researchers' perceptions of self-assembly: Reactions to visual representations of self-assembly*. Paper presented at the 22nd Biennial Conference on Chemical Education (BCCE), State College, PA.

- 2012, Carroll, K., Skaza, H., Crippen, K. J., & Kern, C. *Learning about Climate Change in Death Valley with a Four-Part Blended Inquiry*. Paper presented at the National Science Teachers Association (NSTA), Indianapolis, IN.
- 2011, Carroll, K., Crippen, K. J., Kern, C., & Ebert, E. (2011). *Using Inquiry with Web-based Tools to Teach Science Meaningfully*. Paper presented at the National Science Teachers Association (NSTA) National Convention.
- 2011, Bussey, T., Orgill, M., Crippen, K., Litster, M., Wood, S., Kern, C., & Ho, W. (June, 2011). Defining a “big idea” in nanoscience: Researchers’ identification of the key characteristics of self-assembly. Poster presented at the 2011 Chemistry Education Research and Practice (Foundations and Frontiers) Gordon Research Conference, Davidson, NC.
- 2011, Litster, M., Wood, S. A., Orgill, M., Crippen, K., Bussey, T., Kern, C., & Ho, W. (2011, June). Life scientists’ conceptions of self-assembly. Poster presented at the 2011 Chemistry Education Research and Practice (Foundations and Frontiers)
- 2011, Wood, S., Orgill, M., Litster, M., Crippen, K., Bussey, T., Kern, C., & Ho, W. (2011, March). *Analysis of researchers’ responses to visual representations of self assembly*. Poster presented at the 241st National Meeting of the American Chemical Society, Anaheim, CA.
- 2010, Bussey, T., Orgill, M., Kern, C. L., Crippen, K. J., & Litster, M. *Examining researchers’ perceptions of self-assembly*. Paper presented at the 21st. Biennial Conference on Chemical Education (BCCE), Denton, TX.
- 2008, Ebert, E. K., Kern, C., Mayes, G., Marconi, E., Pollins Bard, H., Doughty, L., Asay, L. D., Crippen, K. J., Bailey, J., Thomas, M., Orgill, M., Waldman, C. A., Messina, F., Reichenbach, R., & Holt, S. (2008, March). *Using action research data to inform instruction: A tale of data sense making*. Presented at the 2008 National Conference of the National Science Teachers Association, Boston, MA.
- 2008, Ebert, E. K., Crippen, K. J., Bailey, J., Thomas, M., Orgill, M., Asay, L. D., Holt, S., Reichenbach, R., Kern, C., Pollins Bard, H., Doughty, L., Mayes, G., Waldman, C. A., Messina, F., & Wagner, C. (2008, March). *Project PASS: Inquiry, conceptual change, and self-regulated learning*. Presented at the 2008 National Conference of the National Science Teachers Association, Boston, MA.
- 2008, Holt, S., Ebert, E. K., Crippen, K. J., Bailey, J., Orgill, M., Thomas, M., Asay, L. D., Kern, C., Waldman, C. A., Messina, F., Pollins Bard, H., & Reichenbach, R. (2008, March). *Project PASS – Researching the role of*

*scientific argumentation in the classroom*. Presented at the 2008 National Conference of the National Science Teachers Association, Boston, MA.

2008, Ebert, E. K., & Kern, C. L. (2008, March). *Friday Symposium*. Paper presented at the 2008 National Conference of the National Science Teachers Association, Boston, MA.

2007, Kern, C. L. (2007, March). *Lord of the Sea Monkeys: Inquiry and assessment*. Paper presented at the 2007 National Conference of the National Science Teachers Association, St. Louis, MO.

### **State & Regional**

2012, Kern, C. L. (2012, April) *The Theory Behind C4D*. Presented at the EPSCoR Tri-State Consortium, Sun Valley, ID.

2012, Kern, C. L. (2012, April) *The Data: C4D studies and findings*. Presented at the EPSCoR Tri-State Consortium, Sun Valley, ID.

2012, Skaza, H. J. & Kern, C. L. (2012, April) *C4D Cyberinfrastructure*. Presented at the EPSCoR Tri-State Consortium, Sun Valley, ID.

2012, Skaza, H. J. & Kern, C. L. (2012, April) *System dynamics: Developing climate change models*. Presented at the EPSCoR Tri-State Consortium, Sun Valley, ID.

2012, Kern, C. L. & Skaza, H. J. (2012, April) *Design framework for C4D*. Presented at the EPSCoR Tri-State Cyberlearning Summit, Albuquerque, NM .

2008, Kern, C. L. (2008, September). *Analogies: A strategy for learning and self-regulation*. Poster presented at the 42nd American Chemical Society Western Regional ACS meeting poster presentation, Las Vegas, NV.

2008, Kern, C. L., & Crippen, K. J. (2008, January). *Mapping for Conceptual Change*. Paper presented at the 2008 Nevada State Math and Science Conference, Las Vegas, NV.

2008, Kern, C. L., & Knox, D. (2008, January). *Bringing GAVRT into science classrooms*. Presented at the 2008 Nevada State Math and Science Conference, Las Vegas, NV.

2008, Kern, C. L., (2008, January). *Inquiry: A strategy for teaching and learning science and math*. Presented at the 2008 Nevada State Math and Science Conference, Las Vegas, NV.