SCAFFOLDING SYSTEMS IN HIGH SCHOOL SCIENCE PROBLEM SOLVING: A CASE STUDY

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Dedicated to my late brother Howard Edwin “Rusty” Berg II.

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Kimberly Farnsworth

SCAFFOLDING SYSTEMS IN HIGH SCHOOL SCIENCE PROBLEM SOLVING: A CASE STUDY

This descriptive case-based study examined the scaffolding practices of a high school science teacher in a problem-based learning (PBL) biochemistry unit. Qualitative methods were used to analyze the scaffolding system used on multiple planes (individual, group, whole class), scaffolding types (hard, soft) and functions (structuring, problematizing) to support learning in the PBL science unit. Teacher perceptions and attitudes related to scaffolding goals were also considered. Data were collected from classroom observations, semi-structured interviews, and lesson artifacts. Findings revealed emergent themes including the teacher's: (1) Use of a dialogic system of scaffolding; (2) shifting between scaffolding planes; (3) incorporating a spectrum of scaffolding types; (4) shifting between problematizing and structuring; (5) perception of scaffolding as an ongoing conversation; and (6) orienting herself in the role of co-learner. Based on these six themes, it was evident that the teacher's scaffolding system was process-drive as opposed to goal-driven and that she used an adaptive system to promote productive struggle.

Implications for classroom practice in similar PBL contexts were described and suggestions included leveraging the problem-solving process for deep understanding, use of an adaptive dialogic approach, positioning teacher and students as co-learners and co-teachers, and becoming comfortable with ambiguity in implementing a scaffolding system. Limitations of the study were noted as well as the potential for this study's findings to contribute to the body of literature on scaffolding complex learning. The findings of this case study revealed a scaffolding

system that was robust and allowed for deep learning and the potential affordances of a process-oriented PBL environment.

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CHAPTER 1: INTRODUCTION

Scaffolding Systems in High School Science Problem Solving: A Case Study

Introduction

This descriptive case study examined a high school science teacher in a problem-based learning (PBL) environment looking at how the teacher scaffolded and supported students' problem solving in a biochemistry unit. The study described was part of doctoral dissertation research for the fulfillment of a Doctor of Education degree in Instructional Systems Technology at Indiana University Bloomington.

As will be described, the learning environment was problem-based which included student-directed, collaborative and complex processes which were scaffolded at various planes using different types and functions of support (Hmelo-Silver, 2004). The context was a two-week PBL unit *Mission to Mars* where students were organized into small collaborative groups to select one of two astronauts – Luna and Orion – to travel to Mars. The problem presented included information about Luna's and Orion's health, personal physical fitness, as well as genetic factors. The content within which the problem was couched was that of the human cell cycle and cancer.

This study was conducted in a 10th grade high school biochemistry class for two days to gather observation data, conduct semi-structured interviews, and collect lesson artifacts in order to answer research questions examining what scaffolding system the teacher used to support learning in this PBL science unit.

Purpose of the Study

The purpose of the proposed study was to describe the scaffolding system that a high school science teacher used in a PBL environment, including the scaffolding planes, types and functions of support provided. Using a descriptive, case-based qualitative approach, classroom observations, semi-structured interviews, and artifact analyses were conducted to consider the scaffolding system from a holistic perspective, taking into account both a priori and emergent themes. This approach focused on three research questions and developed a rich description of the PBL environment and scaffolding system used.

The research questions guiding this study were:

- What scaffolding system does a teacher use at multiple planes (individual, small group, whole class) to support learning in problem-based learning high school science lessons?
- What scaffolding types (hard, soft) and functions (structuring, problematizing) does a teacher use to support learning in problem-based learning high school science lessons?
- How does a teacher characterize the goals and intentions of scaffolding use in problem-based learning high school science lessons?

Research Methods

The epistemological underpinnings of the proposed research were that of constructivism and the socially negotiated process of meaning making (Bruner, 1961; Ertmer & Newby, 2013; Jonassen, 1991). This qualitative case study used a deductive content analysis system with an a priori coding scheme to address the research questions (Cho & Lee, 2014; Kyngäs, 2020). See Appendix A. These codes corresponded with scaffolding planes (individual, small group, whole class), scaffolding types (hard, soft), and scaffolding functions (structuring, problematizing). Data sources included classroom observations, semi-structured interviews, and lesson artifacts which were coded using the coding scheme described.

The observations consisted of two days of high school biochemistry PBL instruction which were part of a larger unit *Mission to Mars.* Prior to and following instruction, semi-structured interviews were conducted with the teacher to gather data focused on the teachers' perceptions of and attitudes toward the scaffolding system she implemented in the PBL lessons. Lesson artifacts were submitted by the teacher for content analysis.

Emergent themes in the findings included: (1) A dialogic system of scaffolding; (2) shifting between scaffolding planes; (3) a spectrum of scaffolding types; (4) shifting between problematizing and structuring; (5) the teacher perceived scaffolding as an ongoing conversation; and (6) the teacher fostered a co-learning environment.

Significance of the Study

Based on these six themes which surfaced during data analyses, the process-oriented nature of the scaffolding system focusing on students' deeper understanding was a prominent pattern that emerged. The teacher used a dialogic approach with frequent problematizing to foster productive struggle in the students' problem solving, while also demonstrating a willingness to adapt and follow the students' lead. This comfort with ambiguity included the teacher's positioning herself as a co-learner and students as co-teachers, shifting as needed between scaffolding planes, types and strategies, and a sustained focus on promoting the problem-solving process. It was the process itself that was the primary means by which the participant teacher fostered students' sense making.

This study adds to the literature on scaffolding systems in complex learning environments, specifically focusing on process-oriented scaffolding and fostering a classroom environment of knowledge co-construction where the teacher takes on the role of a co-learner. I found that productive struggle research was predominantly seen in educational psychology and learning sciences contexts with a few studies found in the K-12 science and math education content areas (Engle & Conant, 2002; Hiebert & Wearne, 2003; Warhsaur, 2015). The literature on teachers positioning themselves as co-learners focused mainly on post-secondary instruction suggesting a potential gap in K-12 research on creating co-constructive environments where the teachers and students are both co-learners and co-teachers (Brantmeier, 2013; Jordan & Schwartz, 2018; Kelly, 2006; Wallace & Loughran, 2012). This case study adds another K-12 perspective to the body of literature on process-oriented and co-constructive scaffolding systems in complex learning environments.

Based on the process-oriented scaffolding system observed and the affordances it provided for deeper learning, implications for classroom practice include suggestions for building similar learning environments. Overall, the findings revealed a rich scaffolding system that fostered deep understanding in the high school science PBL unit as students struggled in productive ways and engaged in co-constructive sense making with peers and the teacher.

CHAPTER 2: LITERATURE REVIEW

Problem Based Learning

The development of problem-based learning as a pedagogical approach was first seen at McMaster University in their newly developed medical program (Barrows, 1986; Hmelo-Silver, 2004; Savery, 2015; Servant-Miklos, 2019; Servant-Miklos et al., 2019). This learning approach continued in medical schools in the 1980s, where instructional activities centered around a problem to be solved (Barrows, 1986).

PBL involves the organizing of a learning environment to foster learning through problem-solving. However, it is more than just presenting a problem for students to solve (Hmelo-Silver, 2004). PBL environments are complex, messy and ill-structured (Glazewski & Hmelo-Silver, 2019; Hmelo-Silver et al., 2007; Kirschner et al., 2006; Savery, 2015). They are student-centered, focused on authentic problems or contexts and seek to promote higher-order thinking in learners and place the instructor in a facilitator role (Hmelo-Silver, 2004; Savery, 2015). PBL also focuses on student reflection of their own learning, open-ended solutions (not one correct answer), and an array of levels of learner support or scaffolding (Hmelo-Silver, 2004; Honebein, 1996; Savery, 2015).

In the PBL environment the learner's prior knowledge and ability level are taken into account, and students drive the learning process as they work in collaborative groups to solve problems. This complex learning approach promotes higher-order thinking skills, cooperative problem-solving, and has as its goal the transition of the learner from novice to expert (Hmelo-Silver, 2013).

PBL in K-12 Environments

Although PBL has historically been used in university preparation programs for professional fields such as medical school (Barrows, 1986), it has become increasingly prevalent in K-12 curricula including in secondary schools (Barrows, 1996; Merritt et al., 2017; Tawfik et al., 2021). In the early 1990s, Howard Barrows, who had actively developed a PBL approach at McMaster University Medical School, and Ann Kelson of Southern Illinois University started working with K-12 public schools in a joint venture The Problem-Based Learning Institute (PBLI) (Barrows, 1996; Barrows & Kelson, 1995). The PBLI developed PBL curricula and teacher training programs, first in science but subsequently in further core disciplines, which were well received by teachers and students in K-12. Barrows (1996) explained that the rapid spread of PBL was due to heightened levels of interest and engagement shown by teachers and students to the new approach.

Torp and Sage (2002) described their work in K-12 PBL research at the Center for Problem-Based Learning at the Illinois Mathematics and Science Academy (IMSA) which began in 1992. They shared that teachers were enthusiastic about integrating PBL into their curricula, but they did struggle with obstacles such as how to manage standardized testing expectations while using PBL. Students in K-12 enjoyed the authentic nature of PBL problems, felt more engaged, and also felt heard by their teachers. Middle school teachers shared that the benefits of PBL extended beyond the classroom impacting students' behaviors in the lunchroom and playground. At the high school level, students expressed an increase in self-efficacy and confidence.

More recently, PBL has been widely adopted in K-12 education and increasing numbers of schools have focused on 21st century skills which have been framed as creativity, problem solving, collaboration, research skills, and critical thinking (Brush & Saye, 2017; Grant &

Tamim, 2019; Larson & Miller, 2011; Savery, 2015; Tawfik et al., 2021). The complex, ill-structured nature of PBL promotes these desired skills and outcomes for K-12 students (Hmelo-Silver, 2004; Savery, 2015; Torp & Sage, 2002). In addition to being adopted across K-12 grade levels, PBL is currently used in multiple content areas including science (Belland et al., 2015; Brush et al., 2016; Brush et al., 2021; Winters et al., 2021), engineering (Farnsworth & Larson, 2020; Larson et al., 2018) social studies (Brush & Saye, 2008; Saye & Brush, 2017), mathematics (Merritt et al., 2017), as well as in the study of many other disciplines and environments in K-12 (Brush et al., 2020; Glazewski & Ertmer, 2020; Hmelo-Silver, 2012).

PBL Outcomes

Merritt et al. (2017) found several positive outcomes from the use of PBL in K-12 education in a review of the literature including increased academic performance, knowledge retention, conceptual development, and attitudes toward scientists and science in general. For example, PBL demonstrated better student academic outcomes than traditional instruction and improved knowledge transfer (Brush & Saye, 2017), increased motivation, and a focus on higher-order thinking skills (Tawfik et al., 2021). Wirkala and Kuhn (2011) found that PBL in a K-12 environment produced higher academic performance in PBL activities than in traditional lecture-based instruction. In addition, Saye and Brush (2017) found that students demonstrated increased empathy after engaging in problem-based historical inquiry.

Barriers to PBL Practice in K-12

Although the literature demonstrates positive outcomes for PBL, there are often barriers to the effective practice of PBL in K-12 classroom environments (deChambeau & Ramlo, 2017; Ertmer & Simons, 2006; Fitzgerald et al., 2019; Strobel & van Barneveld, 2015). Potential obstacles to effective implementation can include a lack of resources and lack of time (Fitzgerald et al., 2019). Another potential barrier is a lack of training or professional development (Brush et al., 2020; Farnsworth & Larson, 2020). PBL requires a high level of experience and expertise to implement (Glazewski & Hmelo-Silver, 2019; Saye & Brush, 2017) and teachers often don't have opportunities for adequate pre-service or in-service training (Dolmans et al., 2002; Puntambekar and Hubscher, 2005). A lack of institutional support for professional development or for the use of PBL in classroom curricula can exacerbate obstacles to effective PBL implementation (Fitzgerald et al., 2019). K-12 teachers often feel a lack of support whether that be from school administration, school culture in general or even at the district level (Park & Ertmer, 2008; Tawfik et al., 2021).

Challenges also exist for the learner when participating in PBL. For example, Strobel and van Barneveld (2015) found that a significant barrier for students was their initial discomfort when first engaging with PBL. The change in the learner's role from passive receiver of instruction to active participant in learning can cause frustration and potentially impact the problem-solving process (Larson et al., 2018; Strobel & van Barneveld, 2015). Part of this shift in roles requires the teacher to position themself as a facilitator, guiding the learner to transition from novice to expert (deChambeau & Ramlo, 2017; Ertmer & Simons, 2006; Hmelo-Silver, 2013).

Scaffolding Systems

Cognitive Apprenticeship

PBL's focus on learner progression from novice to expert involves a transfer of responsibility as the student takes on an apprentice-like role, while the instructor takes on a mentoring role (Collins et al., 1991; Woolley & Jarvis, 2007). Collins et al. (1991) in describing traditional apprenticeships explained that the expert models for the learner how to accomplish certain tasks and they highlighted four key aspects of a traditional apprenticeship: modeling, scaffolding, fading, and coaching. They proposed that authentic approaches to solving real-world problems involve the learner's participation in a cognitive apprenticeship. In this cognitive apprenticeship, the expert (the teacher) makes their *thinking* visible to the learner, not just their actions or tasks. In order to effectively accomplish this, the teacher should: (1) determine which processes are part of the task or learning and make them visible to the learner; (2) anchor tasks that are abstract in authentic contexts enabling learners to understand the importance of the task; and (3) provide a variety of learning contexts related to the task highlighting common features to support transfer of the learning.

In this cognitive apprenticeship framework, the core of the process is founded on modeling, scaffolding, and coaching. Collins et al. (1991) suggested that articulation, reflection, and exploration help to reinforce the learning which occurs at the core of the cognitive apprenticeship process. The whole process is focused on supporting the novice (learner) to become an expert. In PBL the goal of moving the learner from novice to expert lines up with the concept of a cognitive apprenticeship, specifically focusing on how best to support or scaffold the problem-solving process (Hmelo-Silver & Barrows, 2015).

Defining Scaffolding

One of the challenges of PBL is that it is ill-structured; there are many possible solutions to the problems that students are to solve and many ways to arrive at a solution (Hmelo-Silver et al., 2007; Kirschner et al., 2006). Due to the ill-structured nature of problem-solving, a heavy cognitive load is placed on learners as they engage in PBL (Doering & Veletsianos, 2007; Hmelo-Silver et al., 2007; Kirschner et al., 2006). In addition, the learner, when confronted with complex, messy learning tasks, often does not have the adequate content knowledge to know which critical features of problem solving to attend to (Ertmer & Glazewski, 2019; Kim et al., 2018). Further complicating the problem-solving experience, "learning tasks often involve considerable complexity, where multiple disciplines are crossed and knowledge is incomplete in one or more domains" (Land, 2000, p.69).

Wood et al. (1976) in their seminal publication *The Role of Tutoring in Problem-solving* proposed that the teacher should control "those elements of the task that are initially beyond the learner's capacity, thus permitting him to concentrate upon and complete only those elements that are within his range of competence" (p.90). In this way, scaffolding is a means of providing support or guidance for learners as they go through the problem-solving process and develop solutions (Saye & Brush, 2002).

Reiser (2004) described several ways in which scaffolding can support learners in a problem-based environment by structuring the learning task, highlighting key components of the task, scaffolding learner planning, supporting students' performance and understanding, and helping learners manage the complexity of the task. Hmelo-Silver and colleagues (2007) described how scaffolding in PBL can enhance retention and deeper learning by reducing cognitive load. In addition, learners who are supported through scaffolding demonstrate increased performance and improved transfer of problem-solving skills, stronger reasoning strategies and higher-order thinking skills (Cognition and Technology Group at Vanderbilt, 1992; Ertmer & Glazewski, 2015, 2019; Geier, et al., 2008; Lynch et al., 2005; Patel et al., 1993; Vernon & Blake, 1993). Brush and Saye (2008) also found that scaffolded problem solving resulted in an improvement in affective outcomes such as engagement, motivation, and empathy.

Scaffolding Planes, Types and Functions

Research on scaffolding has produced a variety of proposed theoretical frameworks and characterizations of what scaffolding complex learning is, what is important about it, what its key characteristics are, and the intended outcomes of different scaffolding strategies (Belland et al., 2013; Ertmer & Glazewski, 2019; Puntambekar, 2015; Saye & Brush, 2002; van de Pol et al., 2010). Three key aspects of scaffolding, as described below, will be highlighted in this paper and were used as a framework for describing and analyzing the PBL environment in this study.

Scaffolding Planes

Puntambekar (2015) described student scaffolding as consisting of three levels or planes. Puntambekar suggested that students in complex learning environments need to have scaffolding at (1) the individual plane, (2) the small group plane, and (3) at the whole class plane. The instructor provides students with support at those three planes with a variety of scaffolding types which can be instructor-developed scaffolds, technology-based scaffolds, or just-in-time support offered in various forms. Not only do students need to be scaffolded at different planes, but they need a variety of scaffolding tools and resources, which Puntambekar characterized as distributed scaffolding.

Scaffolding Types

Saye and Brush (2002) defined two types of scaffolding that are often incorporated into learning: soft scaffolding and hard scaffolding. Soft scaffolding is operationalized as continuous, dynamic teacher support providing just-in-time guidance and feedback. Hard scaffolding is defined as elements of the learning environment that are pre-planned and anticipate "typical student difficulties with a task" (p.81). In this way, hard scaffolding addresses anticipated needs and emergent needs that students may experience during the inquiry learning process. For instance, an instructor may know that their students have varying levels of prior knowledge needed to access the content of the problem-solving activity and then prepares for anticipated gaps in student knowledge. Soft scaffolding, however, occurs when a gap emerges during the problem-solving process. This need may be perceived by the teacher, the individual student, or even a small group. The just-in-time scaffolding provided is characterized as soft scaffolding and is dynamic, adaptable, and timely.

Scaffolding Functions

Reiser (2004) highlighted two functions of scaffolding: (1) structuring/minimizing task complexity and (2) problematizing relevant task features. Structuring or minimizing task complexity addresses a learner's zone of proximal development (Vygotsky, 1978), bridging the gap between what a student is able to do on their own and what they could do with scaffolded support. This can be accomplished through (1) structuring complex tasks, (2) pre-selecting relevant data, (3) narrowing options, (4) offloading routine parts of a task, and (5) modeling a task or making thinking visible (Ertmer and Glazewski, 2019; Reiser, 2004). A second function of scaffolding identified by Reiser is the problematizing of relevant task features in other words to "guide the learner into facing complexity in the domain that will be productive for learning" (p.288). Ertmer and Glazewski (2019) similarly shared that problematizing surfaces for learners "those parts of the problem they might otherwise overlook" (p.11). This can be done by introducing cognitive dissonance or by engaging learners with controversial ideas that may foster their interest and cause them to confront complexity. "Tutors modulate their support to target an optimal level of difficulty" (Reiser, 2004, p.287).

Productive Struggle. In several studies of K-12 math learning, problematizing is considered key to learners' gaining a deep understanding of the content by fostering *productive struggle* or *productive disciplinary engagement* (Engle & Conant, 2002; Reiser, 2004). Engle and Conant (2002) posited that “by incorporating content and interaction” deep learning can occur as learners productively engage with content in the discipline (p.403). They suggested that productive discourse in a content domain is essential to creating learning environments that foster productive disciplinary engagement or productive struggle. It is this productive struggle through discourse that Engle and Conant suggested demonstrates the importance of both the cognitive and the social in reaching deeper understanding. By struggling in productive ways in a socially interactive environment, learners construct knowledge while problem solving (Bjork & Bjork, 2011; Hiebert & Wearne, 2003; Hmelo-Silver, 2004).

The three aspects of scaffolding described – planes, types, and functions – guided this study’s investigation and description of how scaffolding is implemented in a high school science teacher’s curriculum.

CHAPTER 3: METHODS

Purpose of the Study

This study used a descriptive case-based approach to look in depth at the scaffolding practices of a high school science teacher who was embedded in a school that was supportive of inquiry- and problem-based approaches. The school defined itself by its focus on student-centered, authentic learning in the sciences. The participant teacher had significant resources and was allowed needed time to prepare and implement PBL science lessons. The focus of the research was to study how a teacher developed and implemented a scaffolding system in a high school science PBL curriculum.

The research questions guiding this case study were:

- What scaffolding system does a teacher use at multiple planes (individual, group, whole class) to support learning in problem-based learning high school science lessons?
- What scaffolding types (hard, soft) and functions (structuring, problematizing) does a teacher use to support learning in problem-based learning high school science lessons?
- How does a teacher characterize the goals and intentions of scaffolding use in problem-based learning high school science lessons?

Research Design and Methods

This paper describes a descriptive case-based, qualitative study of how a K-12 teacher supports and scaffolds student learning in a problem-based learning environment. A case study considers context and allows the researcher to "generate rich descriptions to understand bounded complex social systems or processes" such as those that exist in a classroom environment

(Mardis et al., 2014, p.183). The purpose of the case study is to examine a system or a process through a holistic lens, allowing the researcher to engage in concept formation while examining a case through triangulation (Ragin, 1999). Case studies are generally considered to be qualitative in orientation, although mixed methods may be used (Ragin, 1999).

Descriptive Case Studies

Descriptive case studies are characterized by a "rich, 'thick' description of the phenomenon under study" meaning a thorough, full description of a bounded system (Merriam, 1998, p.29). A case can be a person, a group, a program, a community, or any phenomenon that occurs in a specific and unique context. Classroom learning environments, for example, including participants, physical, cultural, and other characteristics, are complex, bounded systems; therefore, the study of a classroom environment is the study of a case. Descriptive case studies are often used when a phenomenon is highly complex, bounded in a context, and difficult to study in another way (Ragin, 1999). In this study, the participant teacher's support and scaffolding of students during PBL lessons involved messy, complex interactions bounded in the context of the learning environment. Although case studies may use any data collection and analysis methods, for the purposes of this descriptive case study, qualitative methods were used (Merriam, 1998).

Qualitative Research Methods

Qualitative research methods are rooted in the epistemological foundation of constructivism and the view that knowledge is socially constructed (Merriam, 2002). Proponents of qualitative research argue that this approach offers distinct advantages compared to other approaches (Creswell, 2014; Fraenkel et al., 2012; Yin, 2016). For example, a qualitative approach allows the researcher to focus "on language and meaning, individual perspectives and beliefs, discourse and social interaction, and emergent group processes and culture" (Mardis et al., 2014, 174). In this study, teacher-student interactions within the natural classroom setting were observed. Further, semi-structured interviews were conducted with the teacher to consider her perspectives and beliefs and how they informed classroom interactions when scaffolding student learning.

Another advantage of a qualitative approach is that it allows room for emergent findings to surface while also affording the researcher the ability to use existing theories or frameworks to guide analyses (Cho & Lee, 2014; Kyngäs, 2020; Merriam, 2002). In this study I used an a priori coding scheme to conduct deductive content analyses of all the data: pre- and post-instruction interviews, classroom observations, and lesson artifacts. Content analysis in qualitative research focuses on using a systematic approach to surface meaning from qualitative data (Cho & Lee, 2014; Kyngäs, 2020). Coding units of meaning in the data reveal both the observable or visible content as well as the underlying or latent meanings in the data. Content analysis can be inductive, where the codes are derived during the data analysis process, or deductive, where a priori codes are used based on existing research or theoretical frameworks (Cho & Lee, 2014; Kyngäs, 2020). In this study, a deductive content analysis approach was used.

The unit of analysis was each instance of scaffolding observed or mentioned during data collection. By using existing theoretical frameworks as a foundation for data analyses, I was able to identify patterns and themes emerging from the data. The intention of using qualitative approaches was to reach a deeper level of understanding about the case studied than could be acquired through other methods. The research questions in this study are well-suited to a qualitative approach as they seek to describe not only how the teacher scaffolds student learning in problem-based lessons, but also the purposes of that scaffolding. The social interactions and the environment as a whole were essential to understanding the findings.

Limitations

This case-based study allowed for deep analysis of one teacher's scaffolding system in a PBL unit. Although qualitative case studies afford a researcher the opportunity to study closely the learning environment and, in this case, the scaffolding system used by the teacher, there are limitations. For example, any findings are not generalizable and can only be interpreted within the bounded context studied (Mardis et al., 2014; Ragin, 1999); the participant teacher and the students were a purposive sample with the teacher having been selected due to her experience as a veteran teacher and specifically her experience with PBL.

Another limitation to be mentioned was the limited observation time. I had planned to observe three days of classes but due to a last-minute change in the school's standardized testing schedule, only two days of observations occurred. Ideally, at least three days would have allowed for further triangulation of data and potentially added to the richness of the findings.

Research Questions

The proposed study examined how a high school science teacher scaffolded student learning in a problem-based learning environment. The types of scaffolding used in this context, the functions of the scaffolding, and at what planes the instructor implemented scaffolding in the classroom were examined. The primary research questions for this study were:

- What scaffolding system does a teacher use at multiple planes (individual, small group, whole class) to support learning in problem-based learning high school science lessons?
- What scaffolding types (hard, soft) and functions (structuring, problematizing) does a teacher use to support learning in problem-based learning high school science lessons?

- How does a teacher characterize the goals and intentions of scaffolding use in problem-based learning high school science lessons?

Context and Participants

Participants and Setting

The primary participants were a high school science teacher, Ms. Juliana Lopez (names were changed to protect participants' privacy), and her students in a public school district in a large metro area in the Southwestern United States. The participant teacher was part of a purposive sample selected due to her experience with complex learning environments, scaffolding, and K-12 science instruction (Fraenkel & Wallen, 2009). The students were tenth graders taking a required, sophomore biochemistry course. The learning environment was a bioscience-focused magnet school for grades 9-12 with a total of 378 students: 113 in 9th grade, 74 in 10th grade, 99 in 11th grade, and 92 in 12th grade. Students applied to enter the school and were primarily from lower socioeconomic backgrounds with sixty-five percent of students receiving free and reduced lunch. Most were first generation students when they moved on to post-secondary education. Seventy-four percent of students were Latinx, twelve percent were White, seven percent were Asian or Pacific islander, five percent were Black, three percent were two or more races, and less than one percent were Native American.

The participant teacher had two biochemistry classes which met every day for 90 minutes with a total of 50 students across both classes. The teacher co-planned the curriculum with another biochemistry instructor who also had two classes meeting for the same length of time. The biochemistry course was a required tenth grade class and formed the foundation for students' selecting a science specialty in their eleventh and twelfth grade years including biomedical research, engineering, and other science disciplines. The curriculum in the biochemistry course was centered in a PBL environment, which was encouraged and supported by the school administration.

Data Collection and Materials

For this study, two days of biochemistry PBL instruction were observed in the teacher's classroom as students engaged with PBL science activities. Each lesson was videotaped with a focus on capturing teacher-student interactions. Prior to instruction, a semi-structured interview was conducted with the teacher to gather data focused on the teachers' perceptions of and plans to scaffold student learning in the PBL lessons. Following classroom implementation of the biochemistry science lessons, I conducted a post-lesson semi-structured interview with the teacher allowing for the participant to reflect on the scaffolding system used during the lessons. The teacher also submitted the lesson plans including pre-prepared hard scaffolds as artifacts for analyses.

PBL Lesson Features

The biochemistry lessons which were taught during the two days of observations were part of a larger biochemistry unit *Mission to Mars*. The unit centered around a problem for learners to solve: Which astronaut, Luna or Orion, should be selected to travel to Mars. This unit was developed by the participant teacher in collaboration with the other tenth grade biochemistry teacher in the school. Learners worked in small collaborative groups to solve the central problem including identifying key elements of the problem, determining what problem-solving strategies to use, reflecting on their own understanding of the content and developing evidence-based solutions. The teacher seldomly used explicit instruction, as the goal was for the students to construct their own knowledge of the given biochemistry phenomenon through collaborative problem solving.

The *Mission to Mars* unit took place over the course of 16 instructional days. Figure 1 below is a timeline of how the unit unfolded. The two days of classroom observations are indicated: Day 14 and Day 15.

Figure 1. Mission to Mars Unit Timeline

Day	Instructional Content	Day	Instructional Content
Day 1	Introduction to Mission to Mars Initial group models	**Day 9**	Cancer questions Cell cycle POGIL
Day 2	What is radiation?	**Day 10**	Enzyme whiteboards Mitosis puzzle
Day 3	Ionizing vs. non-ionizing radiation	**Day 11**	Mitosis modeling
Day 4	Strawberry DNA lab DNA reading	**Day 12**	Mitosis modeling
Day 5	Chromosomes and karyotypes	**Day 13**	Cancer as a genetic disease
Day 6	Mutations	**Day 14**	Classifying cancer genes *****Classroom observation 1*****
Day 7	How are cancer cells different than healthy cells?	**Day 15**	Cell cycle modeling *****Classroom observation 2*****
Day 8	HeLa cells	**Day 16**	Unit Assessment

Study Procedures

Table 1 below outlines the study's data collection and analysis methods organized by research question.

Table 1. Data Analysis Methods

Research Questions	**Collection methods**	**Analysis methods**
What scaffolding system does a teacher use at multiple planes (individual, group,	Pre-lesson semi-structured interview Classroom observations	Deductive content analysis using thematic coding (Kyngäs, 2020; Merriam, 2002) were used to analyze

whole class) to support learning in problem-based learning high school science lessons?	Post-lesson semi-structured interview Artifacts: Lesson plans & scaffolds	pre- and post-lesson interviews, classroom observations, and artifacts.
What scaffolding types (hard, soft) and functions (structuring, problematizing) does a teacher use to support learning in problem-based learning high school science lessons?	Pre-lesson semi-structured interview Classroom observations Post-lesson semi-structured interview Artifacts: Lesson plans & scaffolds	Deductive content analysis using thematic coding (Kyngäs, 2020; Merriam, 2002) were used to analyze pre- and post-lesson interviews, classroom observations, and artifacts.
How does a teacher characterize the goals and intentions of scaffolding use in problem-based learning	Pre-lesson semi-structured interview Post-lesson semi-structured interview	Deductive content analysis using thematic coding (Kyngäs, 2020; Merriam, 2002) was used to analyze pre- and post-lesson interviews.

high school science lessons?		

Data Collection Instruments

In order to answer the study's two research questions, data analyzed included classroom observations, semi-structured pre- and post-instruction interviews, lesson plan and scaffolding artifacts. These data collection methods – semi-structured interviews, classroom observations, and artifact analysis - allowed for triangulation and provided data to inform this study's research questions.

Classroom Observations. I observed two days of PBL science activities in a high school science teacher's classroom. An observation protocol was developed focusing on three thematic elements (Appendix A). The three thematic elements - scaffolding functions, scaffolding types, and scaffolding planes - allowed patterns to surface within each thematic element and across the elements. Other potential themes from the observation data were also considered as they emerged. I used deductive content analysis methods (Kyngäs, 2020; Merriam, 2002), as will be described in this paper, to allow for further themes and patterns to surface from the data and be incorporated into the analysis. The classroom observations were videotaped for data analysis and enabled me to code observed scaffolding instances based on these themes.

Semi-structured Interviews. Prior to lesson implementation, I conducted a semi-structured interview with the participant teacher, Ms. Lopez, to gather data focused on how she planned to scaffold student learning in the PBL science lessons as well as her perceptions and scaffolding intentions. The pre-lesson interview used a semi-structured interview protocol (Appendix B) to gather data on the learning environment and learning activities, anticipated scaffolding to be prepared in advanced, as well as any dynamic scaffolding the teacher perceived would be needed.

A post-instruction interview (Appendix C) allowed the teacher to reflect upon how the lessons unfolded, successes and challenges, how scaffolding supported student needs, and what changes she would (or would not) make to the scaffolding system used in the PBL lessons. In addition, the teacher's perceptions and attitudes toward the scaffolding system she implemented were discussed. The thematic elements described above were used as a framework for analysis, although using deductive content analysis methods (Kyngäs, 2020; Merriam, 2002), I also allowed for further themes and patterns to surface from the data and be incorporated into the analysis.

Artifacts: Lesson Plans and Hard Scaffolds. The participant teacher in this study submitted copies of the problem-based science lesson plans as well as copies of any hard scaffolds prepared for the PBL science lessons implemented. These artifacts were collected for data analysis to further inform the overall deductive analyses (Kyngäs, 2020; Merriam, 2002) using thematic elements described previously (Appendix A).

Data Analysis

Classroom Observations

I conducted a deductive content analysis of the observation notes and video recordings to help deepen understanding of how the teacher used scaffolding during PBL science activities (Cho & Lee, 2014; Kyngäs, 2020; Merriam, 2002). Classroom observation videos were transcribed, and my observation notes were combined with observation transcripts in order to create an overall narrative of the teacher and student interactions within the problem-based learning environment.

Following preparation of observation transcripts, I identified meaning units within the instances of scaffolding that surfaced from the transcripts (Elliott & Timulak, 2005). These were the instances of scaffolding that were observed in the classroom. At this point, I used an a priori coding scheme to code the observation transcripts. A priori themes included: (1) scaffolding plane – individual, small group, whole class; (2) scaffold type – hard, soft; (3) scaffolding function – structuring/minimizing, problematizing (Appendix A). I remained open to adding emergent codes based on any latent meanings surfaced during the analysis. Once the data were coded, several categories emerged. These categories were then analyzed to surface unifying themes evident across all the data which sufficiently described the scaffolding patterns brought to light during content analysis.

Semi-Structured Interviews

Semi-structured pre- and post-implementation interview data were analyzed using deductive content analysis methods (Cho & Lee, 2014; Kyngäs, 2020; Merriam, 2002). The interview audio recordings were transcribed and prepared for coding. Teacher statements and comments were analyzed for meaning units related to how the students' learning was scaffolded (Elliott & Timulak, 2005). Meaning units were the descriptions stated by the teacher of instances of scaffolding and statements she made revealing her perceptions and attitudes towards the scaffolding system used in her classroom. As with the classroom observation data, I used an a priori coding scheme to code the interview transcripts, remaining open to emergent codes which may surface during this process. The coding scheme described previously included scaffolding planes, types and functions (see Appendix A). Once the data were coded, several categories emerged. These categories were then analyzed to surface unifying themes evident across all the data which sufficiently described the scaffolding patterns brought to light during content analysis.

Lesson Plan Artifacts

Similar to the observation and interview data, lesson artifacts were coded using a deductive content analysis approach incorporating a priori themes as an organizing framework to start the analysis process (Choe & Lee, 2014; Kyngäs, 2020; Merriam, 2002). Meaning units identified in the artifacts included in some instances the artifact as a whole and in some cases parts of the artifact, depending on how these related to the coding scheme in use. For example, when coding for scaffolding type (hard and soft), an artifact as a whole might be coded as a hard scaffold. However, some artifacts consisted of different parts that corresponded with different codes. Once the artifacts were coded, several categories emerged. These categories were then analyzed to surface unifying themes evident across all the data which sufficiently described the scaffolding patterns brought to light during content analysis. These artifact data allowed for further triangulation between classroom observation and interview data.

CHAPTER 4: FINDINGS

The Lesson: Mission to Mars

Observations were conducted over the course of two class periods toward the end of a biochemistry unit, *Mission to Mars*. This was a two-week unit centered around the problem of selecting which of two astronauts, Luna or Orion, were most suited to travel to Mars. The students were presented with the full problem including the information that both Luna and Orion had family members who had had cancer, while Luna had a genetic mutation in the P53 gene and Orion did not have any known genetic mutations. See the *Mission to Mars* unit introduction including the problem presentation in Appendix D.

As students started the unit, they worked in small groups to determine what P53 was, what a mutation would mean for someone's health, how genes are affected in both a terrestrial and a space environment, and how the environment in space travel would affect both astronauts. After considering all the factors, students working in small groups were asked to select which astronaut would go to Mars. The groups were asked to justify their choice providing a scientific explanation of how genes affect the cell cycle in humans and, more specifically, in the selected astronaut. Finally, students were assessed individually in a written exam where they were prompted to write a detailed justification for why their group selected the chosen astronaut and how the cell cycle explained their choice.

Thematic Findings

Data were collected from the following sources: classroom observations, semi-structured interviews, and lesson artifacts. Lesson artifacts identified and analyzed included: (1) the *Learning Tracker*, (2) *Cell Cycle Model*, (3) *Cell Cycle Model Template*, (4) *Classifying Cancer Genes Activity Sheet*, (5) *Mission to Mars Introduction*, and (6) *Self-Compassion Stems* slide. All data were analyzed using a priori themes addressing the three primary research questions: scaffolding plane (individual, small group, whole group), scaffolding types (hard, soft), and scaffolding functions (structuring, problematizing). See Appendix A. Also addressed were the teacher's perceptions of the goals and intentions for scaffolding in a PBL lesson.

The findings are organized around each of the research questions looking at corresponding themes drawn from evidence surfaced in each data source. Additional themes that surfaced during analyses also are described.

Research Question 1

What scaffolding system does a teacher use at multiple planes (individual, small group, whole class) to support learning in problem-based learning high school science lessons?

Theme 1: A Dialogic System of Scaffolding through Questioning

The primary scaffolding strategy that Ms. Lopez used at all planes (individual, small group, whole class) was that of questioning. During classroom discussions, Ms. Lopez used a dialogic approach with the whole class to "move the discussion forward" as she explained in the post-lesson interview. As will be described, classroom observations also revealed the heavy use of questioning and discussions at the small group plane, as well.

I observed that Ms. Lopez appeared to use class level discussions, small group discussions and activities, and individual scaffolding as part of an ongoing conversation between her and the class; a conversation that continued over the course of the whole unit with the goal of guiding their problem solving and promoting deep understanding.

Whole Class Scaffolding. During Day 1 and Day 2, the heavy use of questioning and classroom discussion were evident. Ms. Lopez initiated discussions by asking open-ended questions that were intended to guide students at the whole class plane, and she also used questioning as a means to check for understanding. For example, during Day 2 in Period 2, the teacher noticed some misconceptions that the students were having as they worked on their models. She initiated a whole class discussion using questioning to scaffold the students' understanding:

> MS. LOPEZ: Okay. So let's kind of put some of our ideas together, because I think this might help us with where you guys are stuck…So what did you guys discuss [in your groups] that you wanted to show in space happening?
>
> ISAAC**:** In space you have to show that ionizing radiation is damaging.
>
> MS. LOPEZ**:** Alright, so Isaac says for sure we have to have radiation in space damaging. Do you guys want to add and make it more specific? Evan?
>
> EVAN**:** The radiation will mutate another gene that's necessary for cancer to happen.
>
> MS. LOPEZ**:** So we need to show radiation mutating a gene - another gene. What do you mean another? Why do you say another?
>
> EVAN**:** Because on the thing we did yesterday…you needed multiple genes to have cancer alongside P53.
>
> MS. LOPEZ**:** So we need to show, like Isaac is saying, radiation damaging another gene. Not P53. Because what? What do we need to show next? Marcus?
>
> MARCUS**:** My idea would be try not to have any mistake in the cell cycle like in the beginning and [inaudible] that cannot fix that and then it goes on.

By soliciting participation from multiple students, both those who volunteered as well as some who she asked to share, the scaffolded discussion surfaced the key features of cancer cell growth by identifying the role of environment (radiation in space), genetic mutation, and specifically how a mutated P53 gene might affect the cell cycle.

Interviews. During semi-structured interviews, Ms. Lopez talked at length about her use of questioning as a scaffold at the whole class plane. In both interviews (pre- and post-lesson), she shared her intentional use of a questioning as part of a dialogic approach. For example, she explained the importance of preparing and using questions:

> So I have discussion questions prepared. I also just have for me, like, questions that I want to make sure we look at.

Ms. Lopez further shared an example of how she used questioning in a whole class discussion and what her intentions were:

> I asked them, "Does Luna have the P53 gene?" And of course they were like, "Yes!" And then I was like, "Do you have the p53 gene?" And they're like "I don't know." And…so I wanted to make sure that was really clear.

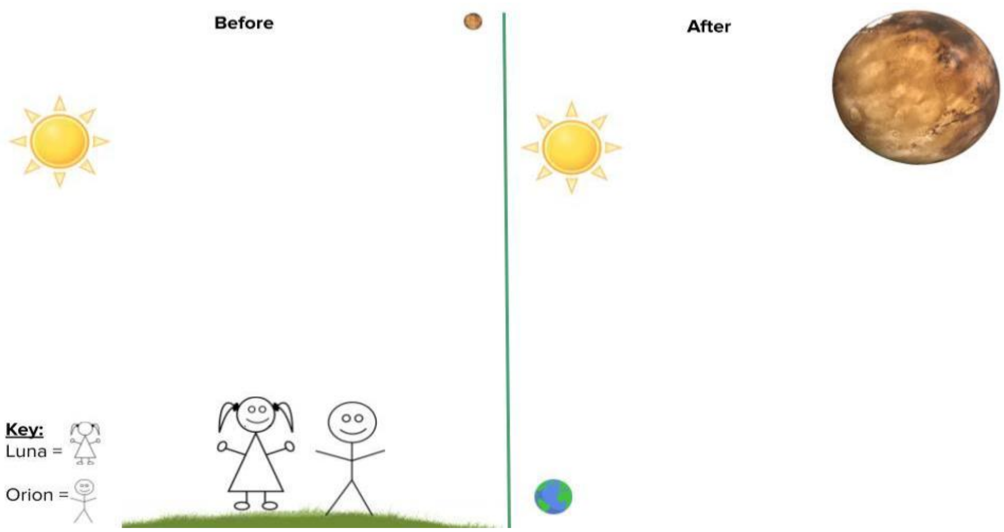
Small Group Scaffolding. In conjunction with whole class scaffolding, Ms. Lopez also scaffolded at the small group plane primarily through questioning. This questioning took the form of just-in-time support as well as pre-planned hard scaffolds as will be described.

Interviews. Ms. Lopez mentioned her use of small group scaffolding several times during both interviews, pre- and post-lesson. During the pre-lesson interview, one of the instances of small group scaffolding that she discussed was the groups' development of conceptual models in the form of posters. Each group developed their *Cell Cycle Model* throughout the unit which continued during both days of observations - Day 1 and Day 2. See Figures 2 and 3.

Each group's *Cell Cycle Model* was developed over two weeks of instruction and were in the form of posters (see Figure 2). Small groups were to illustrate why Luna or Orion should be chosen as the astronaut to go to Mars. The *Cell Cycle Model* needed to illustrate how the P53 gene mutation that Luna had would impact this choice (see Figure 3). Small groups demonstrated what happens in the cell cycle and how a P53 mutation would affect the cycle in Luna versus not having the P53 mutation (Orion). In addition, the groups were asked to illustrate if there were differences in the cell cycle processes on Earth versus in space.

Figure 2. Cell Cycle Model Group Poster

Figure 3. Cell Cycle Model Template



During the pre-lesson interview, Ms. Lopez explained how she viewed the small group models as a form of scaffolding:

> So their model…it's all just like scaffolding them and…hopefully they understand what we've been trying to get them to. Like, 'Yeah, it's okay, like take a risk on your model. What do you think is happening? Draw something. Go with it, discuss it. If it doesn't work, revise it.'"

She added during the pre-lesson interview the way that the small group scaffold of the *Cell Cycle Model* would require them to move a little beyond their zone of proximal development:

> The confusing part is they're going to model. They already have started their models, like, over this whole unit; every time they learn something they kind of add it to their model. So, they have a picture of Luna and Orion on Earth. I think most of them have a picture of, you know, they zoomed in on Luna's cell and they say like, "Luna has a mutation on this chromosome, on this gene, on Earth." And now they're going to have to model what happens in space.

Observations. The primary scaffolding strategy Ms. Lopez used to scaffold small groups was through questioning, as she had at the whole class plane, as well. She often asked questions during group work to guide students. For instance, while groups worked on developing their *Cell Cycle Models* during Day 2, Ms. Lopez walked from group to group observing their models and how they were progressing. She noticed some issues with Group 2's model:

> JAILEN: For the cell cycle we're showing how P53 can get out of hand and get out of control.

MS. LOPEZ: Ok, so if you're trying to show it, getting out of hand, would you just show a cell cycle kind of going crazy?

JAILEN: Uh, we're just gonna show mitosis. We're not gonna show…

MS. LOPEZ: OK, so you're just going to show mitosis. How would I know it's getting out of hand like if I was looking at your model? How would I know, like, that mitosis is…?

JAILEN: Um,

MS. LOPEZ : Like what would I see?

JAILEN : So…um…

MS. LOPEZ: If somebody…if you're trying to communicate to somebody, like, this mutation is causing this cell replication to go uncontrolled. It replicates uncontrollably. I mean, how would you show that?

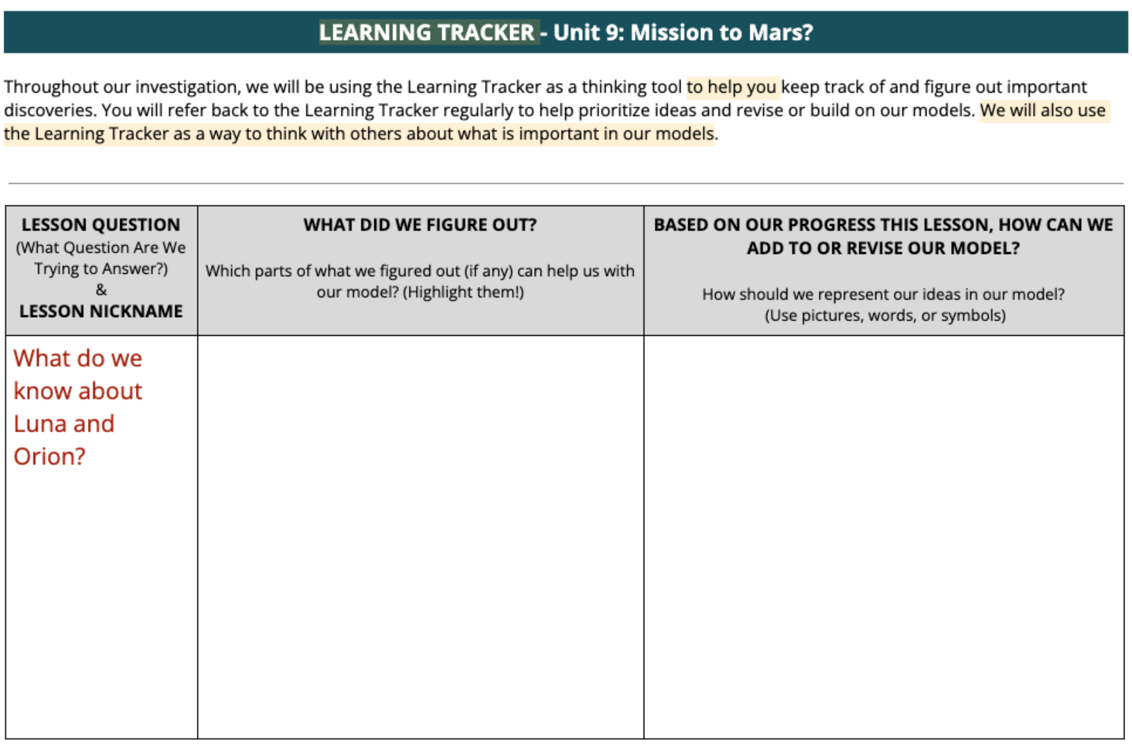
JAILEN: Uh, probably zoom into, like, the checkpoints and…like… I don't know.

MS. LOPEZ: Does that make sense what I'm asking? Cause it's like if I didn't know anything and I would just look at your model and be like, "Looks like mitosis." Right? So what else would I need to see in order to know that's not the way mitosis is supposed to work?

This use of questioning to surface key features continued in a back-and-forth exchange between Ms. Lopez and the small group members until they were able to identify how the checkpoints, which are part of the cell cycle, related to uncontrolled mitosis. At that point, Ms. Lopez moved to another group because she perceived that the group would then be able to determine how to illustrate that in their model on their own.

Artifacts. As described above, one scaffold used throughout the unit at the small group plane was the *Cell Cycle Model*. The models were a key scaffold in the PBL unit as groups worked through activities and discussions. They used both the *Learning Tracker* and a *Gotta Have Checklist* to identify and detail what they needed to include in their group's visual model and how to demonstrate that. The *Learning Tracker* (see Figure 4) was used both individually and in small groups. An example of small group use was at the end of the first day of instruction, groups were asked to use the *Learning Tracker* to "decide what we have learned and needs to be included in your model. How does your group plan to model it?" This included groups asking: "What question are we trying to figure out?"; "What did we figure out?"; and "Based on our progress this lesson, how can we add to or revise our model?".

Figure 4. Learning Tracker



LEARNING TRACKER - Unit 9: Mission to Mars?

Throughout our investigation, we will be using the Learning Tracker as a thinking tool to help you keep track of and figure out important discoveries. You will refer back to the Learning Tracker regularly to help prioritize ideas and revise or build on our models. We will also use the Learning Tracker as a way to think with others about what is important in our models.

LESSON QUESTION (What Question Are We Trying to Answer?) & **LESSON NICKNAME**	**WHAT DID WE FIGURE OUT?** Which parts of what we figured out (if any) can help us with our model? (Highlight them!)	**BASED ON OUR PROGRESS THIS LESSON, HOW CAN WE ADD TO OR REVISE OUR MODEL?** How should we represent our ideas in our model? (Use pictures, words, or symbols)
What do we know about Luna and Orion?		

The *Cell Cycle Model* was not intended to be the final assessment or outcome of the unit, but Ms. Lopez intended it to be a form of scaffolding to guide learners in selecting either Luna or Orion as the astronaut who would travel to Mars based on their findings. Although the models were shared with the class at the end of the unit, they also had a final written assessment where each student was asked to explain the cell cycle and how mutations affect cell growth, specifically in the case of cancer.

Limited Individual Scaffolding. At the individual plane, very little scaffolding was observed during the four classroom observations. Similarly, Ms. Lopez only discussed individual scaffolding one time during semi-structured interviews. However, more than one of the artifacts coded during data analyses were individual plane scaffolds.

Interviews. Ms. Lopez did not address individual scaffolding in the pre-lesson interview. However, in the post-lesson interview, she reflected on her tendency to implement mostly small group and whole class scaffolding. Ms. Lopez also commented on her goals for small group scaffolding and how they relate to individual scaffolding:

> That's typically what my small group scaffolding is for….to bring them [struggling students] up to basically, like, to where we were all on the same page… I don't have as many individual scaffolding tools.

Observations. During classroom observations, individual scaffolding generally occurred as a result of Ms. Lopez's perceiving gaps in understanding that surfaced in whole class discussions and small group work. This individual plane of scaffolding used hard scaffolds such as the *Learning Tracker* to promote reflection and support the learners in identifying key features of the problem.

For example, when Ms. Lopez perceived that students were not understanding how genetic mutations might affect cell growth, she implemented a flipped classroom activity having students individually watch a video the night before class. When students arrived to class (Day 1 in both classes), they used the *Learning Tracker* to scaffold their knowledge construction by having them answer several reflection questions individually (questions identified further in Artifacts section below). Once students had answered these questions individually, they then met in their small groups to further elaborate on these questions and their answers.

Theme 2: Shifting Between Scaffolding Planes

A prominent pattern that emerged from the data analysis was Ms. Lopez's switching back and forth between different scaffolding planes. She was observed shifting between small group and whole class scaffolding throughout both days of observations and in both classes. She shifted between whole group, small group and individual scaffolding usually in a preplanned system. As in the use of the *Learning Tracker* described above, she planned for individual plane scaffolding to be completed and then shifted to using the *Learning Tracker* with the small group to further support their problem solving. She also moved from whole class scaffolding, often in the form of a dialog, to small group scaffolding.

Ms. Lopez shared during the pre-lesson interview how she intentionally planned this shifting between scaffolding planes:

> It'll be back and forth. So small group, whole group and so often I'll have…some discussion questions on the board for their small group and then we'll come together, as a whole group. Yeah, it'll be kind of like that.

She further illustrated how she used this strategy in the post-lesson interview:

> I also try my best to, you know, when I do notice that no one knows or maybe they're not sure… they're not wanting to say, then I'll say. 'Okay, well, talk to your groups and then let's talk after you do that.'

Ms. Lopez shared one of the reasons for moving between whole class and small group during the post-lesson interview:

Just trying to make sure, like, everybody is a part of learning. Which is why…asking a question of the class and having them discussed in small groups is nice, because it makes me feel the big classroom discussion is nice, but I also get the same kids [responding].

Observations. On Day 1 of observations in Period 5, this pattern of shifting between whole class scaffolding in the form of dialog to small group scaffolding was evident:

MS. LOPEZ: [In whole class discussion]. Do we understand why you need to repair them? What does that mean? What is genome maintenance?

NAYELI: It’s like when it’s repairing damage.

MS. LOPEZ: Repairing damage? So why would there be damage in the DNA?

NAYELI: Because of ionizing radiation.

MS. LOPEZ: Maybe. What else?

ISAIAS: Polymerase makes mistakes sometimes.

MS. LOPEZ: Polymerase makes mistakes sometimes, and it's pretty easy. There's lots of nucleotides to add. It's going to make a mistake…How many mistakes does it typically make?

JONATHAN: One in a billion.

MS. LOPEZ: So I want you to discuss that [in small groups]. How do genes involved in cell growth and survival, cell fate, and cell maintenance cause cancer? Why would the mutation affect cancer specifically?

At this point, the class separated into their groups to continue the discussion about how genes affect the cell cycle and how that related to Luna and Orion. In this example, the teacher shifted from a whole class discussion to small group collaboration. However, the reverse often occurred, as well. On Day 1 of classroom observations in Period 2, Ms. Lopez noticed some misconceptions during small group work and had the groups stop working so the class could discuss as a whole group. She asked one group to share what they were discussing in order to surface the misconception and then used questioning to scaffold students' understanding of ionizing radiation.

> JORGE: What my group said was that Luna is not at risk for skin cancer because, you know, skin cancer doesn't involve the P53 gene.
>
> MS. LOPEZ: That's good to know, okay. Daniel?
>
> DANIEL: Well, it's just a thought. We don't actually know for certain, but maybe she still could get skin cancer because she's still going and being exposed to ionizing radiation. And you don't necessarily need to have a mutated P53 gene to get skin cancer.
>
> MS. LOPEZ: Okay? So what I hear Daniel saying is that we know Luna has a mutated P53 gene. A mutated P53 is not associated with melanoma. However, Daniel's saying she's going to be exposed to ionizing radiation which can cause a mutation… Something that I wanted to mention. Are we only looking for melanoma? Where did you guys get stuck that she got melanoma or that melanoma is somehow involved here?
>
> TATIANA: So I did a little independent research, but I first thought that, ionizing radiation, I thought of it as being similar to, like, the UV rays on earth, which could cause skin cancer. I forgot that it hits different, you know?
>
> MS. LOPEZ: [Laughs and restates] Ionizing radiation hits different.
>
> TATIANA: And, so, it wouldn't cause just skin cancer.

> MS. LOPEZ: I think, yeah…so maybe that's where you guys are thinking and confusing UV light and ionizing radiation.

This pattern of shifting between scaffolding planes was not only evident during classroom observations, as has been detailed, but Ms. Lopez clarified that this was intentional and part of a planned scaffolding system.

Research Question 2

What scaffolding types (hard, soft) and functions (structuring, problematizing) does a teacher use to support learning in problem-based learning high school science lessons?

Theme 3: A Spectrum of Scaffolding Types

Data analyses revealed a range of scaffolding types from just-in-time soft scaffolding seen during classroom observations, often in the form of questioning, to hard scaffolding that was pre-planned in anticipation of needs that the learners may have as they problem solve. Also observed was a type of scaffolding that seemed to be somewhere between just-in-time classroom scaffolding and planned hard scaffolding. This scaffolding type was adaptive in nature but also planned in advance of classroom instruction, a form of adaptive hard scaffolding, and will be described here.

Hard Scaffolds: Anticipatory and Adaptive. Several hard scaffolds were implemented by Ms. Lopez, both pre-planned prior to the start of the *Mission to Mars* unit, as well as those prepared in response to problem-solving gaps perceived by Ms. Lopez during the unit. Each type of hard scaffolding will be described below. The hard scaffolds identified included: the *Learning Tracker*, *Gotta Have Checklist*, *Cell Cycle Model*, and *Classifying Cancer Genes Activity*. Several of these have been described in a previous section; however, each will be briefly described here also.

Anticipatory Hard Scaffolds. Examples of anticipatory hard scaffolding included the *Learning Tracker*, the *Gotta Have Checklist* and the *Cell Cycle Model*. The *Learning Tracker* was created by Ms. Lopez and her co-planning teacher prior to starting the *Mission to Mars* unit. The purpose was to support learners in identifying key features throughout the problem-solving process. Guiding questions to be used at both the individual and small-group planes were incorporated into a handout that students used every day to guide the development of the *Cell Cycle Model*. This scaffold was developed in advance of the unit and in anticipation of support that learners would need.

Similarly, the *Gotta Have Checklist* was a scaffolding strategy developed by Ms. Lopez and her co-planning teacher prior to beginning the unit. Small groups were asked to list information and key features that they "gotta have" in their final *Cell Cycle Model*. Throughout classroom activities, discussion, and group activities, Ms. Lopez continually reminded students to develop the *Gotta Have Checklist* and refer back to it as they developed their models.

As described at length above, the *Cell Cycle Model* was a small group scaffold requiring learners to work collaboratively to illustrate the cell cycle and how it affected two astronauts, Luna and Orion, who each had different genetic profiles. The model was not intended to be used as an assessment but as a means to scaffold learners' surfacing of key features in the cell cycle to help them select which astronaut should travel to Mars. This scaffold was developed prior to the start of the *Mission to Mars* unit by both Ms. Lopez and her co-planning teacher and was a central part of the unit. Both teachers anticipated not only the learners' needs in the problem-solving process but provided a pre-planned method of scaffolding the small groups' efforts.

Adaptive Hard Scaffolds. Ms. Lopez had several hard scaffolds, some of which were adaptive in nature and developed after she perceived a gap in students' understanding or emerging misconceptions. In the course of the learning process, learning gaps or misconceptions surfaced and Ms. Lopez developed hard scaffolds before the following class to support the learners' problem solving. These adaptive hard scaffolds were pre-planned but were also a form of just-in-time support in the sense that they were developed in response to gaps emerging from one day to the next.

One example of a hard scaffold developed in response to a perceived gap during the problem-solving process was the *Classifying Cancer Genes Activity* (see Appendix E). During the pre-lesson interview, Ms. Lopez explained her concern that students had developed a misconception about the genetic component of cancer and how she responded by creating the *Classifying Cancer Genes Activity* for the next day of class.

> I really want to, like, break this misconception. [Luna's] dad and grandfather had cancer and [Orion's] grandmother had cancer, so they keep saying…'Luna inherited cancer or got cancer. She's going to get cancer from her dad', or something like this, like, she's inheriting cancer.

In response to this perceived misconception, Ms. Lopez decided to develop an activity to surface important features of how genetic mutations play a role in cancer development. She described during the pre-lesson interview how she wanted to scaffold using intentional questioning in conjunction with the *Classifying Cancer Genes Activity*.

> And so tomorrow I want to start that discussion of, "What does that mean that cancer is genetic?" Like, "She is getting it from her dad?" They're going to look at a lot of different genes that, when they're mutated, can lead to cancer, that you can inherit the mutated version of these [genes]...So they're going to kind of visualize it like the entire genetics, right, like where they are.

[Removed Strawberry DNA Lab description and data]

Soft scaffolding. As was mentioned previously, Ms. Lopez used a dialogic approach of questioning at the whole class plane and at the small group plane. Although she did prepare some questions in advance as a form of anticipatory hard scaffolding, the majority of questioning was in the form of just-in-time soft scaffolding at both planes.

Observations. During Day 2 in class Period 2, as students were working in small groups, Ms. Lopez noticed one group arguing about the different types of tumors and their role. She used questioning to provide just-in-time soft scaffolding guiding the group in resolving their disagreement and surfacing a key characteristic of cancer:

JULIETA: [Arguing with a group member] No, but not all tumors are…

MS. LOPEZ: Well, how did we define cancer earlier?

JULIETA: Uncontrollable cell growth

MS. LOPEZ: [Restating] Uncontrollable cell growth. So it's that uncontrolled cell division?

JULIETA: Uh-huh. And it can end in… that…?

MS. LOPEZ: It can result in a tumor.

ISAAC: Ok, so cancer is the act of that? Like, the cell growth happening? It’s just the result of that?

MS. LOPEZ: Yeah, mmm hmmm, yeah.

Interviews. During the Post-Lesson Interview, Ms. Lopez explained how she identified when soft scaffolding was needed and how she used it:

> I'll just, like, listen for something that I know is going to get us to the next thing. I'm like, ‘Okay, let's grab onto that and let's go from there.’

Ms. Lopez further explained in the Post-Lesson Interview how she used questioning as a form of soft scaffolding.

> I was also looking for their understanding of cancer. So some of them, some of the groups, were showing like P53, I don't know, checking DNA or something and it finds a mistake and then there's cancer. I was like, "Oh wait! I think you're missing something. Like, just finding a mutation makes cancer? What's happening here?" And so that's kind of like all I was doing during that time was walking around and I would just basically be asking them a bunch of questions…I'll just usually, like, say out loud what I see. I'll say, "It looks like this, this and this." And they're like, "No!" "Well, that's what I see. What are you trying to represent?" Just to help them really solidify their overall understanding, so they could put it all together for themselves.

Theme 4: Shifting Between Structuring/Minimizing and Problematizing

During classroom observations, I noticed that Ms. Lopez shifted back and forth between problematizing and structuring/minimizing. For example, she would ask a question that introduced complexity (problematizing) and use that as a starting point for a discussion and would continue asking questions as students answered and asked questions themselves. Once she perceived that the feature or concept had surfaced, she would then structure or minimize by providing information or an activity that would fast-track the learners' understanding of the feature or concept.

The opposite was also observed where Ms. Lopez started by structuring or minimizing and once she perceived the learners were progressing, she would then push them further by problematizing as evidenced below while the students were working in small groups on their *Cell Cycle Models*:

> MAGDA: Do you want to check if we missed anything?
>
> MS. LOPEZ: You want me to check if you missed anything? I feel like you can check that. Did you include everything on the *Gotta Have Checklist*? Is it clear? So I'll read it to you [from the group's *Gotta Have Checklist*], "Radiation damaging another gene that's not P53." And you need to show that that gene is a segment of DNA. So where is radiation?
>
> MAGDA: It's here [pointing to model]
>
> MS. LOPEZ: Oh, that very faint squiggly line?
>
> NOEMI: [Speaking to rest of group] Let's make that slightly more obvious.
>
> MS. LOPEZ: So then you're showing that… it says you're showing radiation damaging another gene, and I guess I'm assuming this is the ATC gene and it's damaging it. So how are you representing damage?

At this point, she switches to problematizing by asking a probing question to the group:

> MS. LOPEZ: So, like what is damage? What does it mean when DNA is damaged?
>
> RYAN: A little …like they get mixed up. The ends can get broken.
>
> MS. LOPEZ: So, how do you show that?

Problematizing occurred often in the form of questioning. Ms. Lopez used questioning to prompt classroom discussions and to scaffold small groups' problem solving, as well. One of the ways in which she used questioning included its use to surface relevant features of the problem:

In Day 1 Period 5, Ms. Lopez started the class by asking several questions which prompted a back-and-forth dialogue surfacing key features of the P53 gene and the cell cycle, which were key to deciding which astronaut should go to Mars.

> MS. LOPEZ: So what's the difference [between a tumor suppressor gene and an oncogene]? Can you kind of tell us, like, how they differ?
>
> AMELIA: …OK, it's… P53 is supposed to slow down the cell cycle and check for mutations, while cyclin D1 accelerates the cell cycle?
>
> MS. LOPEZ: Yeah, do guys agree?
>
> NAYELI: Like in the video [students watched the previous day], he said the gas pedal and the brake will like to accelerate or slow it down….
>
> MS. LOPEZ: Either they function to regulate cell growth and survival or they function to regulate cell fate, which is differentiation. So what is differentiation?
>
> DAVID: Like, the cell's task.
>
> MS. LOPEZ: The cell's task. Anybody want to add to that?
>
> JAILEN: The state that it's in, like, either it's programmed to die or it's just going through the cycle.
>
> MS. LOPEZ: So, maybe, how it's growing? OK, Eva?
>
> EVA: Um, it starts as a stem cell and then it kind of gets its function of what it should be and then at the end it dies.
>
> MS. LOPEZ: Ok, so differentiation is basically, or the cell fate is about the cell turning into the type of cell that it's supposed to be, the tasks it supposed to do with the function…Now, one thing to note is when a cell differentiates, it typically stops dividing. All right, and genome maintenance. Do we understand

why you need to repair them? What does that mean? What is genome maintenance?

EVA: Repairing damage..

ISAIAS: Repairing damage. So why would there be damage in the DNA?

ISAAC: Radiation.

MS. LOPEZ: Maybe. What else?

In the post-lesson interview, Ms. Lopez explained further why she uses scaffolding to problematize. She shared that her partner teacher, with whom she co-plans lessons, didn’t want to have students learn about the different types of genes that modulate cancer, specifically oncogenes, as they were already learning about tumor suppressor genes. The partner teacher was concerned that by adding complexity, the students would focus on oncogenes in the assessment instead of on tumor suppressor genes. Ms. Lopez shared her view that by adding complexity, the students would better understand the role of tumor suppressor genes:

> I don’t mind if they write about oncogenes while explaining…if they’re talking about them…this one tumor suppressor does this unlike an oncogene…that’s good. I like that idea. Maybe it helps them better understand what a tumor suppressor does if they understand. I don’t think it did take away from their understanding of their models…I thought it was important that they get the big picture and they see. I just felt like it was important for the bigger picture.

Also in the post-lesson interview, Ms. Lopez described the use of the *Learning Tracker* as a scaffolding tool to problematize and guide students in checking their own understanding and determining how to proceed with problem solving:

> Every day, when we were doing the *Learning Tracker*, the third column is based on [the groups'] progress in this lesson: How can we add or revise our model? So every day, when they're answering a new question or they have ended a lesson, they think about, "What did we do that day? What did we figure out? What's the new information? And then what would that look like on our model? We have to write it out." That's really when they get to discuss with their group mates. Like, "Well, we know we want to put these checkpoints in our cell cycle. What does that look like on our model?"

Research Question 3

How does a teacher characterize the goals and intentions of scaffolding use in problem-based learning high school science lessons?

Theme 5: The Teacher Perceived Scaffolding as an Ongoing Dialog with Learners

As described in previous sections, classroom observations revealed a pattern of Ms. Lopez's using whole class discussions as a dialogue between her and the learners. She shared in the semi-structured interviews that she saw her role as being that of a guide and a dialogic approach as a means to scaffold learners as they problem solved. This was evident not only during the interviews, but also throughout the classroom observations. Ms. Lopez expressed that questioning was a way to: (1) Surface relevant features of the problem, (2) conduct formative assessment, and (3) model effective problem solving.

Surfacing Relevant Features of the Problem. During the pre-lesson interview, Ms. Lopez described how questioning was an intentional scaffolding strategy both as part of an ongoing whole class dialogue, but also as part of the groups' problem-solving process:

> Yeah, so, for these past few units, I have the students kind of keep track of the questions they've been asking and the questions we kind of come to as a class; what's relevant for figuring out what's next here?...I'll ask them what questions do they still have. Sometimes, I will be like, "I feel like before we can get there, we need to first answer this question, right?” So, most every day or most activities are based around a question we need to answer in order to figure out the big like...we're breaking the big question down into many little questions.

In the post-lesson interview, Ms. Lopez further shared her insights into the purpose of using a dialogic approach:

> I'm hoping that with these questions that they're making the connections themselves more than me making for them…We want them to develop the ability to pick out the important information.

Scaffolding as Formative Assessment. Ms. Lopez also discussed in the post-lesson interview how a dialogic approach with the heavy use of questioning helped her formatively assess students’ progress, “Also for me too, it's so helpful for me to know what, where they're at, if I can see their thinking.”

Modeling effective problem solving. The use of intentional questioning had the added purpose, according to Ms. Lopez, of modeling for students the questions they should be asking themselves to guide the problem-solving process. She explained in semi-structured interviews that she wanted students to learn to ask productive questions of themselves and in small groups to focus on deeper understanding and to be able to transfer to various contexts.

In the pre-lesson interview, Ms. Lopez shared the importance of student understanding, "We didn't have them memorize or assess on anything like that…I would harp on it, 'What's happening in prophase? What's happening?'"

She further explained how her use of questioning modeled the problem-solving process for students:

> You're doing this modeling the kinds of questions [students] can ask [themselves]. Like [directed at students], "I can ask you these questions and listen to the questions I'm asking. I'm not asking you anything that you can't ask yourself. Like, 'Why am I thinking that?' Or 'What does that relate to? Does that connect to anything I've learned previously?'"

Theme 6: The Teacher Fostered a Co-Learning Environment

Another theme that emerged during data analysis was Ms. Lopez's use of empathic strategies to put herself in the role of a co-learner as a means of scaffolding student problem solving. Classroom observations revealed her intentional use of taking on the role of student, demonstrating empathy, humility and restating to confirm understanding of what students were saying. In addition, during semi-structured interviews, Ms. Lopez put herself in the role of the learner as a planning strategy.

Empathy and Humility. Ms. Lopez often used empathetic phrasing to take on the role of a learner during classroom discussion. Examples of this phrasing included:

> *Day 2 Period 2:*
>
> > I am confused by that sentence. I am confused about this. What are you talking about? I don't know how to represent this, but I know it's important.

In this first example, Ms. Lopez did know how to represent the cell cycle that the students were attempting to illustrate in their *Cell Cycle Models*; however, she put herself in the role of a learner thereby positioning the group members as tutors to explain it to her.

> *Day 1 Period 2:*
>
> > So he kept saying that cancer is a genetic disease and I felt confused by that because I thought I couldn't get cancer from my mom. Like, if my mom has cancer, I don't think I was going to be born with it. I thought that's what genetic meant.

Again, in this example Ms. Lopez did know what "genetic" meant and how it related to cancer being called a genetic disease; however, she took on the role of a learner positioning the whole class, in the classroom discussion, as tutors.

In addition to demonstrating the use of role switching during classroom observations, Ms. Lopez discussed, during the post-lesson interview, the use of empathy in planning her curriculum.

> When we [Ms. Lopez and co-planning partner teacher] plan the overall unit, we think about the questions they're going to ask us and try to go from there. Like, what would they do after they learn that? What would they be curious about? What might they want to know?

Ms. Lopez and her co-planning partner teacher used this strategy of putting themselves in the place of the learner as part of their regular planning. At another point in the interview, she explained the intentionality of positioning learners as teachers:

> I'm trying to make the lesson, make it their lesson...So I really want them to feel like they're doing the teaching in some ways, right?

Another strategy Ms. Lopez used to position herself on an equal footing with the learners was the use of humility. During classroom observations, a student asked her a question that she didn't know the answer to and she openly admitted her not knowing while at the same time recognizing the student's accomplishment in noticing the discrepancy:

> *Day 1 Period 6*:
>
> I'm not sure, so that's something I don't know. I don't know why they're ordered in this order…I actually don't know the answer to that. That's good noticing, but I don't know why.

Ms. Lopez shared another example during the pre-lesson interview:

> I have this one student, Miguel, who just knows everything. I'm like, "It's okay. Tell us Miguel. What are you thinking?' Better than it coming from me and me being the only person that knows.

The use of empathy in the learning process was also evidenced in the *Self Compassion Stems* artifact which Ms. Lopez had used during the unit, prior to classroom observations, to help students with their feelings of being overwhelmed by the problem-solving task ahead of them. This was in the form of a Google Slides presentation which she had shared with the class. The following statements were displayed to demonstrate self-compassionate thinking:

> *Self-Compassion Stems*
>
> - I've done my best!
> - Everyone finds learning new things hard.
> - I don't have to be perfect.
> - We all make mistakes sometimes.

- It's OK that I'm developing my understanding. I'll try again and keep learning to become proficient.
- I'm a good and lovable person. I will succeed.
- I put in a lot of effort during this unit. I'm proud of myself!

Struggles with Fully Relinquishing Control. Although Ms. Lopez sought to create a co-learning environment in her classroom, she appeared to struggle with fully relinquishing control of the learning process. This was evident in her need to time classroom activities.

During both days of classroom observations, Ms. Lopez incorporated the use of timers controlling the length of activities, specifically small group and individual activities. She used a timer app displayed on her smart board which sounded an alarm at the end of each allotted time period. On the one hand, her use of adaptive scaffolding strategies were meant to foster student-led learning; however, she appeared to be very concerned with how much time students spent engaged in each activity.

During Day 1 toward the end of Period 5, the students were working in small groups to discuss observations they had about where they saw P53 mutations when different forms of cancer occurred. They had only been discussing for two minutes when Ms. Lopez announced, "OK, let's kind of wrap up our conversation because we still have one more thing to do here today."

In another instance during Period 2, also on Day 1, she asked students to move from a whole class discussion to small group work. She said, "Let's take just four minutes to do this. So, four minutes starting now." She then started the timer which counted down on the smart board while they worked. After four minutes, the alarm sounded loudly and students stopped the small group work. This pattern of telling students how much time they had for a given activity, starting the timer countdown on the smart board, and then the sounding of the alarm happened repeatedly in each class period observed.

During the post-lesson semi-structured interview, Ms. Lopez shared that the PBL unit had generated deep learning in her students and their understanding of the cell cycle and its role in cancer growth. She also shared, however, that she was concerned about covering all of the required material for the school year:

> [PBL] takes longer than a typical unit would. Like this year we're going to miss out on [evolution]…We did like no ecology. We're just hoping they know food webs and food chains. Like the big stuff, they're not getting that at all. So, it's like pros and cons.

CHAPTER 5: DISCUSSION

The findings revealed six emergent themes which included: (1) A dialogic system of scaffolding; (2) shifting between scaffolding planes; (3) a spectrum of scaffolding types; (4) shifting between problematizing and structuring; (5) the teacher perceived scaffolding as an ongoing conversation; and (6) the teacher fostered a co-learning environment. Based on these six themes which surfaced during data analyses (semi-structured interviews, classroom observations, and artifacts), it was evident that Ms. Lopez's scaffolding system was highly adaptive, changing from one day of instruction to the next, and that the problem-solving process was more than a means to reach an instructional goal.

Scaffolding For Deep Understanding: Process-Driven vs. Goal-Driven

Ms. Lopez's system of scaffolding student problem solving was complex, intentional, adaptive, anticipatory and centered around the use of dialogue as a means of scaffolding. However, her use of dialogue was more than a goal-oriented strategy; it was a form of scaffolding the process of problem solving. The process itself was the focus.

As described, Ms. Lopez viewed scaffolding as an ongoing unit-long dialogue between her and the learners. She leveraged the role of process in forming deep understanding in her students as they worked to solve the problem at hand - selecting which astronaut, Luna or Orion, should travel to Mars. Although the learners were given this as their goal, Ms. Lopez designed the scaffolding to be an intentional process of sense making. As she stated in the semi-structured interviews, "I'm hoping that…they're making the connections themselves." She further explained the intention of the students' developing "understanding" of the cell cycle and the role it plays in cancer.

As opposed to the problem-solving process being a means for learners to reach a learning goal, in the case of the *Mission to Mars* unit, the process provided a context in which the deep understanding could be developed. In other words, the goal was not to find the best astronaut, it was to develop a deep understanding of the content.

Dialogic Scaffolding as Learning Process

As revealed during data analyses, Ms. Lopez was intentional in her desire to use dialogue as an ongoing conversation progressing throughout the unit. This dialogue was part of a process in which she shifted between scaffolding planes, scaffolding types, and scaffolding functions. Ms. Lopez promoted dialogue through the heavy use of questioning. She used whole class discussions and the pre-planned use of questions to problematize, formatively assess students' understanding, and foster the problem-solving process. Each class started with reflection questions which students answered individually, then in small groups, finally having a whole class discussion where she continued questioning and probing students. The dialogue, then, was part of the process of sense making. (Hmelo-Silver & Barrows, 2008).

Ms. Lopez used several discursive strategies to scaffold learning in classroom discussions. One strategy she frequently used was that of revoicing or restating what a student had just said (Hmelo-Silver & Barrows, 2006). This allowed her to highlight key concepts, validate student input, and guide the overall conversation. Another strategy she used was the reflective toss which Hmelo-Silver and Barrows (2006) described as taking "the meaning of a student statement and [throwing] responsibility for elaboration back to the student" (p.22). The teacher in this study used this strategy repeatedly allowing students to develop shared sense making, examine other perspectives, and allowing them to struggle in productive ways.

Productive Struggle

Ms. Lopez shared in semi-structured interviews her desire to foster students' independent sense making and development of deep understanding by "making the connections themselves more than me making [the connections] for them." As discussed, she used questioning as a scaffolding strategy with the intention of promoting productive struggle by requiring the learners to determine for themselves what they had learned, what they needed to learn, and how these things could be applied to the model-building in which they were engaged (Engle & Conant, 2002; Ertmer & Glazewski, 2019; Reiser, 2004).

Productive struggle occurs when learners are allowed to work at optimal levels of difficulty within the zone of proximal development (ZPD), which is defined as the learning space between what the learner can accomplish on their own and what they can do with support (Reiser, 2004; Vygotsky, 1978). Due to the heavy cognitive load required in complex learning, a learner may struggle to the point of becoming overwhelmed (Ertmer & Glazewski, 2019; Hmelo-Silver, 2004); however, struggling in productive ways can lead to deeper understanding and learning (Bjork & Bjork, 2011; Hiebert & Wearne, 2003; VanLehn et al., 2003; Warhsaur, 2015). Engle & Conant (2002) explained that productive struggle includes problematizing content and giving students autonomy over their learning, as well as adjusting and adapting the support to ensure a productive level of difficulty. By not only allowing but promoting productive struggle in the problem-solving process, Ms. Lopez encouraged her students to develop a deeper understanding of the cell cycle and its role in cancer.

In addition to supporting students' problem solving through the dialogic use of questioning, Ms. Lopez also modeled for students how to ask productive questions of themselves to promote deeper learning, understanding, and transfer to various contexts. As she shared:

> You're doing this modeling the kinds of questions [students] can ask [themselves]. Like [directed at students], "I'm not asking you anything that you can't ask yourself. Like, 'Why am I thinking that?' Or 'What does that relate to? Does that connect to anything I've learned previously?'"

Problematizing

As part of a scaffolding system that promoted productive struggle, Ms. Lopez added complexity to the learning process by problematizing. In semi-structured interviews, Ms. Lopez characterized the use of problematizing as a means for students to "really understand" the concepts. As described in the findings, she co-planned much of the *Mission to Mars* unit with another teacher who was teaching a different section of the same course. During a co-planning meeting, Ms. Lopez explained that she thought the students would better understand the overall focus of the unit - how mutations in tumor-suppressor genes affect the development of cancer - if they were to also learn about oncogenes, thereby adding complexity to the upcoming lesson. The co-planning teacher expressed concern that it would confuse students and take the focus off tumor-suppressor genes and ended up not choosing to highlight oncogenes.

Ms. Lopez, however, explained that she felt that students would "better understand what a tumor suppressor [gene] does" if they learned about oncogenes. She felt that by highlighting these genes' different functions, it would help students to gain a deeper understanding of the cell cycle's role in cancer growth. She also shared in semi-structured interviews that based on student responses on the final written assessment, students demonstrated a deep understanding of tumor suppressor genes' role in the cell cycle and the differences between oncogenes and tumor suppressor genes.

Accepting And Leveraging Ambiguity

Ms. Lopez's scaffolding system was flexible and responsive in that it moved with the students' progress to provide a wrap-around system of support. Ms. Lopez used repeated patterns of scaffolding moving from whole class to small group back to whole class planes of scaffolding, from structuring/minimizing to problematizing and back to structuring/minimizing, This movement from one plane to another and from one scaffolding strategy to another demonstrated her willingness to accept and leverage ambiguity.

Ms. Lopez demonstrated her comfort with ambiguity and ability to shift and adapt to the needs of her students beyond a single class period, adapting from one day's class to another. This was evident in the findings, for example, when she noticed that her students had developed a misconception about how cancer was inherited. Several students made statements in class discussions that one of the astronauts "inherited cancer" from a grandparent. Ms. Lopez was concerned that the students believed cancer itself was passed down genetically.

In response, she developed an activity the day before the next class introducing the learners to various gene mutations that cause different types of cancer. In this situation, her goal was for the students to surface key features of the cell cycle and how genetic mutations can cause cancer. In the class discussion following the activity, Ms. Lopez used questioning to highlight the role genetic mutations play in the cell cycle. This, then, led the students to arrive at the conclusion themselves that cancer-causing gene mutations can be passed down to subsequent generations, not that cancer itself was passed down genetically. By adding a new activity in response to perceived misconceptions, Ms. Lopez not only met the needs of her students, but she fostered student autonomy and productive struggle by allowing them to surface the information through problematizing.

Ms. Lopez also demonstrated her comfort with ambiguity by shifting frequently between hard and soft scaffolds, different scaffolding planes (whole class, small group, individual), and between scaffolding functions (problematizing, structuring). For example, Ms. Lopez began each class period asking students to work in their groups collaboratively to discuss and answer the questions in the *Learning Tracker*. Following the small group work, Ms. Lopez brought students back to the whole group as a class and asked students to report out their thoughts. She promoted a class discussion using questioning to surface their progress as a whole group, their understanding of the cell-cycle and how tumor suppressor genes, such as P53, play a role in cancer development.

This shifting and adapting that Ms Lopez did throughout the unit between scaffolding planes, types and functions demonstrated her willingness to follow the students' lead. As she anticipated the needs of her students, she modified, adapted, and shifted gears all with the primary goal of deepening students' understanding of the content.

Knowledge Co-Construction: Co-Learning and Co-Teaching

Ms. Lopez used the discursive nature of the scaffolding system to position herself as a co-learner working with the students, and she both expressed and showed empathy in how she approached learners. She used empathetic questioning, where she placed herself in the role of a student while asking questions. For example, she used phrases suggesting that she was also engaging in the learning process: "I wonder what that means when the doctor says cancer is genetic"; "I feel like I don't understand"; "Yeah, I wondered that, too. Josue, what do you think?" She already knew the answers to these questions, but she used this repositioning of roles to foster an environment of co-learning and co-teaching *with* her students (Engle & Conant, 2002). [Cut out 2 paragraphs about radical empathy and power structures in the classroom]

Semi-structured interviews revealed her empathetic approach and her desire to position herself as a co-learner in planning, attempting to anticipate students' thinking, and pushing the "conversation" forward, as she stated. Having learners reach that deeper understanding was at the center of Ms. Lopez's scaffolding system and her goals for scaffolding.

Barriers to Implementing a Co-Learning Environment

In this study, the teacher, Ms. Lopez, demonstrated empathy and humility promoting a co-learning environment; however, she did appear to struggle somewhat with fully relinquishing control of the learning process as seen by her need to precisely time classroom activities. Brantmeier (2013) suggested that "positioning oneself as a co-learner when teaching requires much unlearning of cultural conditioning related to the teacher as knower of all; it challenges the traditional authoritative, dominant and subordinate role sets in schooling environments" (p.5). Ms. Lopez seemed to be grappling with her own desire to maintain a dominant role in controlling the timing of classroom activities, while also wanting to promote an equitable co-learning environment.

Given that K-12 teachers are often faced with imposed time constraints and a need to cover specific content due to standardized testing expectations, Ms. Lopez's concerns about timing may also be due to these external pressures (deChambeau & Ramlo, 2017; Ertmer & Simons, 2006; Fitzgerald et al., 2019; Hmelo-Silver, 2013; Torp & Sage, 2002). As she shared in semi-structured interviews, one of her concerns was the amount of time PBL units take when compared to more traditional teaching methods. Ms. Lopez explained that her sophomore students had developed a deep understanding of the content areas covered in the PBL units; however, she felt that they were ill-prepared in other areas because they did not have time to cover those topics. She felt pressured to cover certain content within the school year based on standardized curriculum expectations.

Implications for K-12 Classroom Practice

This study considered the scaffolding approach of a veteran high school science teacher in a PBL unit. As has been discussed, the teacher, Ms. Lopez, used a dialogic approach to engage learners in the problem-solving process with the focus on developing deeper understanding of the content. The process itself was as important, if not more so, than the desired learning outcomes for the unit in that it was the problem-solving process that was intended to promote deeper understanding. As part of that process, Ms. Lopez fostered a co-learning and co-teaching environment in her classroom.

The scaffolding methods and techniques described in this study may provide insight for other teachers in similar contexts. There are four suggested strategies for using such an approach: (1) Leveraging the problem-solving process for deep understanding; (2) a dialogic approach; (3) fostering a co-learner and co-teaching environment; and (4) accepting ambiguity.

Leveraging the Problem-Solving Process for Deep Understanding

In order to implement these strategies, a teacher can plan the PBL unit or lesson to center around the problem-solving process and utilize scaffolding to foster productive struggle. For example, the teacher can use intentional questioning to add complexity and nuance to the content, allowing learners to grapple with the complexity of the learning at hand by problematizing. In this way, the learning becomes student-centered by transferring responsibility and giving them ownership over their own learning (Hmelo-Silver, 2004).

Ms. Lopez used a process-oriented scaffolding system by developing scaffolds that were used throughout the unit such as the *Learning Tracker* as a daily reflective tool or the *Gotta*

Have Checklist to identify important concepts needed to complete their group models. The *Cell Cycle Model* was also used as a process-oriented scaffold supporting groups in their knowledge construction and allowing them to demonstrate that conceptual knowledge.

Classroom teachers can implement process-oriented scaffolding systems in their own instruction by considering not only the problem space, which includes the problem to be solved and the necessary resources to solve it, but also the conceptual space which includes alternate explanations and concepts related to the problem (Hmelo-Silver, 2013). The *Cell Cycle Model* used in Ms. Lopez's biochemistry unit allowed the students to work in the problem space but also provided a rich conceptual space for them to consider alternate hypotheses and basic concepts related to gene mutations and cancer growth.

A Dialogic Approach

In order to foster productive struggle, Ms. Lopez used classroom dialogue to accomplish several things: (1) Problematize content; (2) highlight key features of the problem; (3) promote collaboration among students; (4) formatively assess their learning; (5) make students' thinking visible; (6) model effective problem solving; and (7) position herself as a co-learner and students as co-teachers. The use of classroom discussion or dialogue to promote deeper learning requires preparation of questions and activities that add complexity in a thoughtful way to guide learners to discover key features of the problem. One example of this would be the integration of reflection questions, as Ms. Lopez did, at the start and end of each class with the *Learning Tracker*, as described previously.

Another potential affordance of a dialogic approach is making both student and teacher thinking visible. As Ms. Lopez used classroom discussions to ask productive questions that required learners to struggle, their thinking was made visible to their classmates and to the teacher. This can allow for a type of formative assessment but, more to the point, it allows learners to recognize their own thinking and problem solving. Likewise, by making the teacher's thinking visible, learners can also compare their process with the teacher's.

Fostering a Co-Learning and Co-Teaching Environment

One of the scaffolding strategies that Ms. Lopez used which was evident in the data analysis was her use of role switching. She often positioned herself as a co-learner with the students by asking reflective questions to initiate discussions. For example, she started one class period by asking, "I felt confused by that because I thought I couldn't get cancer from my mom." As described in the findings, Ms. Lopez already understood the concept of how genetics affected cancer, but she positioned herself as a learner and asked the class to explain the concepts to her. The learners then became co-teachers, as well. Using a co-learning/co-teaching approach allows students to maintain ownership over their learning while providing scaffolding from a position of equal footing.

In order to create a co-learning/co-teaching environment, a teacher can use classroom dialogue and questioning to position themself as being a part of the group of learners. Using language that denotes empathy and humility is one strategy that teachers can use to foster this kind of environment and may have the added benefit of promoting engagement and self-efficacy during the problem-solving process.

Ms. Lopez also made it clear to students that their effort of productive struggle mattered by sharing *Self-Compassion Stems* or statements including: "I've done my best"; "everyone finds learning new things hard. I don't have to be perfect"; "we all make mistakes sometimes; it's OK that I'm developing my understanding"; "I'll try again and keep learning to become proficient;

I'm a good and lovable person. I will succeed"; and "I put in a lot of effort during this unit. I'm proud of myself!"

As the teacher positions themself as a co-learner, allows students to be co-teachers, uses empathetic strategies, and provides positive reinforcement for productive struggle regardless of the learning outcomes, the PBL environment becomes one that is focused on deep understanding and meaning making. The process becomes the focus of both the scaffolding system and the problem solving.

Accepting Ambiguity

A teacher can remain flexible not only in their role, but also in how they accept and adapt to ambiguity. As seen in this study, Ms. Lopez was very comfortable with ambiguity and adapting from class period to class period to meet students' needs. Her scaffolding system can be described as one that moves with the students, even following the students' lead. When she perceived a learning gap or that the students had a misconception, she modified her scaffolding system whether that meant developing a new line of questioning, introducing problematizing through new activities, or creating new hard scaffolds just in time.

When prioritizing process and deep understanding over predetermined outcomes and goals, a teacher should be ready to become comfortable with change and ambiguity. Although extensive planning in PBL is important, part of that planning should include making changes as needed. Following the students' lead as they move through the problem-solving process may not result in an anticipated outcome; however, if the teacher holds the view that development of a deeper understanding of the content is the priority, then sticking to a predetermined path of learning is not necessary nor perhaps desirable.

Some of the strategies that Ms. Lopez used to plan adaptively included collaborating with a colleague to share ideas, reflecting after each class period, identifying misconceptions or knowledge gaps held by students, developing questions to initiate classroom discussion in the next class period, and shifting between various scaffolding planes, types and strategies. In addition to planning adaptively, it is important that the teacher adapt during the learning process, as well, following the students' lead as they also work to become comfortable with ambiguity.

Conclusion

The purpose of the proposed study was to describe the scaffolding system that a high school science teacher used in a PBL environment, including the scaffolding planes, types and functions of support provided. Using a descriptive, case-based qualitative approach, classroom observations, semi-structured interviews, and artifact analyses were conducted to consider the scaffolding system from a holistic perspective, taking into account both a priori and emergent themes. This approach focused on three research questions and developed a rich description of the PBL environment and scaffolding system used.

Emergent themes in the findings included: (1) A dialogic system of scaffolding; (2) shifting between scaffolding planes; (3) a spectrum of scaffolding types; (4) shifting between problematizing and structuring; (5) teacher perceived scaffolding as an ongoing conversation; and (6) the teacher fostered a co-learning environment. Based on these six themes which surfaced during data analyses, a pattern emerged demonstrating that Ms. Lopez's scaffolding system was process oriented with a focus on students' deeper understanding.

She used a dialogic approach with frequent problematizing to foster productive struggle while being comfortable with ambiguity and demonstrating a willingness to adapt. This flexibility in how Ms. Lopez scaffolded student learning incorporated her switching roles, positioning herself as a co-learner and students as co-teachers. She also shifted as needed between scaffolding planes, scaffolding types and strategies with a sustained focus on promoting the problem-solving process. It was the process itself that was the primary means by which Ms. Lopez fostered students' sense making.

Based on the process-oriented scaffolding system observed and the affordances it provided for deeper learning, four strategies for classroom implementation of a process-oriented scaffolding system were proposed: (1) Leveraging the problem-solving process for deep understanding; (2) a dialogic approach; (3) fostering a co-learner and co-teaching environment; and (4) accepting ambiguity.

This case study found that a high school science teacher, Ms. Lopez, used a robust scaffolding system which allowed for deep learning. The findings add to the overall body of literature on scaffolding in complex learning environments and the potential affordances of a process-oriented and co-learning/co-teaching PBL environment. In addition, suggestions for implementation of a similar scaffolding system may be leveraged by teachers who wish to develop supports for their learners in complex learning environments.

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APPENDICES

Appendix A. Deductive Coding Scheme

Deductive Coding Scheme: Observations, Interviews, Artifacts		
Scaffolding Type		
Code	Scaffolding Type	Definition
H	Hard Scaffolding	Preplanned scaffolds that anticipate student difficulties.
S	Soft Scaffolding	Continuous, dynamic support. Just-in-time guidance/feedback.
Scaffolding Plane		
Code	Scaffolding plane	Definition
I	Individual	Scaffolding provided to individual learner.
G	Small Group	Scaffolding provided to a small group.
C	Whole Class	Scaffolding provided to the whole class.
Scaffolding Function		
Code	Scaffolding Function	Definition
SF	Structuring/Minimizing	Simplifying a task, helping student do what they are not able to do on their own.
PF	Problematizing	Drawing attention to problem features through cognitive dissonance or engaging controversial ideas.
Note: Sources Ertmer & Glazewski (2019), Saye & Brush (2002), Shin, Brush & Glazewski (2020), Puntambekar (2015)		

Appendix B. Pre-Lesson interview Protocol

Pre-Lesson Interview Protocol
Introduction & Demographics
• Please describe your experience and background as a science teacher. • How long have you been teaching? • In what contexts have you taught? (Content, grade level(s), location) • How does your experience inform your teaching methods today?
Learning Environment
• Please describe the school where you are teaching. • What grade level do you teach? • How many students are in your classes? • How often do classes meet? • What content area do you currently teach? • What is the learning environment like in the school? • How would you describe the learning methods you use in your curriculum?
Learning Activities
• You mentioned that you use [blank] learning methods in your curriculum. • Please describe in more detail what that looks like in a typical lesson. • What is your role in that environment? • What is the student's role? • How much of your curriculum is explicit instruction? • How much of your curriculum would you say is student-directed?

Scaffolding
• When using the learning methods you previously described, how do you support students in their learning? • How much of that support system is prepared in advance? • What does that support look like during the classroom lesson? • How do you know when students need extra guidance or support? • Please share some examples of instances when you have perceived learners needed support and how you addressed their needs.
Expectations
• Looking forward to the lessons you will be teaching during my observations: • Please describe the activities, the learning goals, and overall parts of the lessons. • Please describe any supports you have prepared in advance. • Please describe any needs you anticipate your students having and how you will address those needs. • What are you concerned about when thinking ahead to the lessons? • What do you anticipate will go well?

Appendix C. Post-Lesson Interview Protocol

Post-Lesson Interview Protocol
Initial Thoughts and Impressions
• Please describe your general impressions of how the lessons went. • Did things go to plan? • What things didn't go to plan?
Learner Needs
• Please describe some of the learning needs that your students had during the lessons. • What were some of the learning gaps that you perceived? • How did you address those gaps?
Scaffolding
• When using the learning methods you previously described, how did you support students in their learning? • How much of the support your provided was prepared in advance? • How did students use those prepared supports or scaffolds? • How did you know when students needed extra guidance or support? • How did you provide guidance to your students during the classroom instruction? • What outcomes were you hoping for by providing those supports? • Please walk me through your thought process when you recognized that students needed guidance or support and how you provided that support. What were your thoughts at each point in the process?
Expectations

● Looking forward to future lessons you will be teaching with similar methods: ● What do you plan to do again or incorporate again in similar lessons in the future? Why? ● What do you plan to change or do differently in similar future lessons? Why?
Closing Questions
● Do you have questions for me? ● How did you feel things went in terms of participating in the study? ● Do you have any concerns or recommendations?

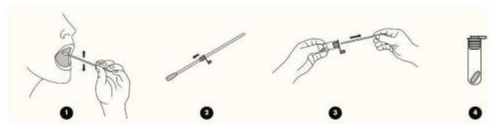
Appendix D. Mission to Mars Unit Introduction

Mission to Mars

The year is 2040. 71 years after Apollo 11 landed on the moon, the United States has finally made technological advancement for the first ever manned mission to Mars. This mission is very crucial to help people determine the livability of Mars. A group of astronauts have applied to participate in this important mission. However, they must go through a series of physical tests before they could be selected to go through a 20-month training to obtain the essential skills needed to travel to Mars.

Traveling to Mars is not an easy task. There are many challenges this human mission must overcome. One of the challenges is the physical harm of exposure to high-energy cosmic rays and other ionizing radiation might pose to the astronauts. During the training session, the astronauts who are physically qualified will learn about what kind of radiation will penetrate the spaceship and how exposure to the radiation might affect them.

Luna and Orion both are young astronauts who have applied to the program. The two of them have very different lifestyles and grew up in different environments. Luna is a healthy eater and runs regularly. Orion, on the other hand, likes to eat fried food even though he is still fit. They both have 20/20 vision and are qualified for the mission in terms of their height, blood pressure and education. The genomic test is the only thing left for both Luna and Orion before they become crew members of this Mars mission. In order to construct Luna and Orion's genomic profile, both of them were sent a kit by NASA to collect their DNA. The kit had the words "Buccal Swab" written on it and contained a pair of latex gloves, a small plastic tube, a long cotton swab, a return envelope, and a set of instructions. The collection process was pretty simple. All they had to do was swab the inside of their cheek with the cotton swab and then put the cotton tip inside the plastic tube (Figure 1). After the two had returned their buccal samples to NASA, they were called to go to the local medical center for a consultation with a genetic counselor.



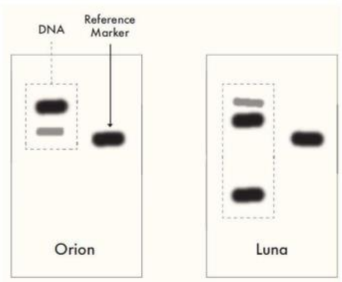


Figure 2. The genetic counselor shows this diagram to Luna and Orion to explain that they were able to detect differences in Luna's genomic profile.

First, they were asked to fill out a questionnaire regarding their family medical history. Luna's father was diagnosed with pancreatic cancer several months ago, and her paternal grandfather died of colon cancer a couple of years ago.Orion's grandmother died of brain cancer 3 years ago. After filling out the forms, the counselor started to inform Luna and Orion about genetic testing. The genetic test was only for common mutations in the tumor suppressor *p53* gene. The results show that Luna tested positive for a *p53* mutation.

Exposure to ionizing radiation, such as that encountered by astronauts in outer space, would greatly increase one's chance of developing cancer. And back here on earth, exposure to ultraviolet (UV) radiation from the sun (or tanning beds!) increases our risk of skin cancer. Luckily for many people, we have a protective mechanism against UV-induced skin cancer. We get some protection from a brown pigment in our skin called melanin, which increases when we are exposed to UV light, to help block the harmful radiation from penetrating the skin. Another protective strategy is the use of sunscreen—and sunblock is even better!

As the mission director at NASA, construct a scientific explanation to determine which astronaut(s) you will select for the manned mission to mars.

Astronauts

Orion

____

____

Luna

____

____

Identify important scientific vocabulary:

Questions

Appendix E. Classifying Cancer Genes

ACTIVITY 1: CLASSIFYING CANCER GENES

INTRODUCTION

You may have read articles that talk about "cancer genes." But what exactly are cancer genes and what do they do?

In this activity you will examine the locations throughout the genome of genes that when mutated cause cancer to develop (i.e., cancer genes) and you will learn about the normal functions of these genes.

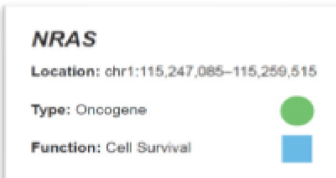


Figure 2. Example of a cancer gene card

You will receive 2-3 Cancer Gene Cards. Each card (Figure 2) contains the gene symbol (abbreviated name, e.g., RB1, BRCA1), the gene's human chromosome location, gene classification (oncogene=circle or tumor suppressor=hexagon), and the cellular processes in which the gene is involved (cell survival, cell fate, or genome maintenance).

Part 1: Using the information on your cards, mark the locations of your genes on the Human Chromosomes sheets. Once you've located a gene, you will further identify it by indicating

- whether the gene is a tumor suppressor gene (red) or an oncogene (green) and
- which functional categories the gene is associated with: cell survival (blue), cell fate (purple), and/or genome maintenance (yellow).

Part 2: Now you will examine the cancer data on your cards collectively, as a class. Using the information on your cards, record the type of cancer gene (tumor suppressor or oncogene) and the gene function(s) indicated on your cards by filling out the google form on Canvas.

Part 3: Analyze the different gene mutations involved in various types of cancer using the data sheet below

Cancer Type	Sample	Genes					
Lung cancer	1	*NF1*	*SETBP1*	*TP53*			
	2	*EGFR*	*MLL2*				
	3	*CTNNB1*	*KRAS*	*NF2*	*TP53*		
	4	*KT*	*MEN1*	*MLL3*	*TP53*		
Breast cancer	1	*BRCA1*	*TP53*				
	2	*CDH1*	*PIK3CA*				
	3	*ARID1B*	*TP53*				
	4	*FGFR2*	*GATA3*				
Colorectal cancer	1	*APC*	*TP53*				
	2	*KDM6A*	*KRAS*	*PIK3CA*	*SMAD4*		
	3	*APC*	*ATM*				
	4	*BRAF*	*CARD11*	*GNAS*	*PIK3CA*	*SMAD4*	*TP53*
Glioma	1	*CIC*	*IDH1*	*PIK3C5*			
	2	*CBL*	*TP53*				
	3	*ALK*	*ATM*	*BRCA1*	*TP53*		
	4	*HNF1A*	*PTEN*				
Melanoma	1	*BRAF*	*CREBBP*	*EP300*			
	2	*FGFR2*	*MLL3*	*NRAS*	*PTCH1*		
	3	*BRAF*	*APC*	*BCOR*	*JAK3*	*MLL2*	
	4	*BRAF*	*CDKN2A*	*MLL3*	*ATM*	*PAX5*	
Hepatic cancer	1	*ARID1A*	*ARID2*	*BRCA1*	*RB1*	*TP53*	
	2	*CTNNB1*	*MED12*				
	3	*HNF1A*	*TP53*				
	4	*ARID2*	*AXIN1*	*JAK2*	*TP53*		
Pancreatic cancer	1	*APC*	*GNAS*	*KRAS*	*RNF43*		
	2	*KRAS*	*TRAF7*	*TP53*			
	3	*CDKN2A*	*KRAS*	*MPL*	*TP53*		
	4	*KRAS*	*SMAD4*	*TP53*			
Leukemia	1	*MYD88*	*SETD2*				
	2	*BCOR*	*NOTCH1*				
	3	*BRAF*	*FAM123B*	*KRAS*			
	4	*NOTCH1*	*PIK3CA*	*TP53*			

K I M B E R L Y   F A R N S W O R T H

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Education

Ed.D. Instructional Systems Technology
Indiana University
Expected graduation June, 2023

M.Ed. Educational Technology
Arizona State University – 2003

B.A. Spanish & Language in Computers
Secondary Education
Brigham Young University – 1996

Experience

Educational Technologist
Department of Defense Education Activity
[Feltwell, UK]
2021 – present

- Support technology-rich curricular planning
- Mentor faculty in tech integration
- Scaffold student technology-enhanced learning experiences

Education Coordinator
Center for Bio-mediated and Bio-inspired Geotechnics (CBBG)
Arizona State University
[Tempe, Arizona, USA]
2019 – 2021

- Coordinated education outreach activities.
- Conducted and published research on inquiry-based STEM education.

Adjunct Faculty / Course Representative
Brigham Young University - Idaho
[Online, Remote]
2016 - 2019

- Participated in online course design and improvements.
- Taught online English 100- and 200-level courses.

Instructional Designer/Developer
Stratus Consulting
[Cave Creek, Arizona, USA]
2015 – 2019

- Designed and developed eLearning and online training modules
- Programmed custom elements in Java

Substitute Teacher
Brighton School District 27J
[Brighton, Colorado, USA]
2011 – 2015

- Taught preK-12 throughout district
- Primarily taught ESL and Special Education

Graduate Research Assistant
Arizona State University
[Tempe, Arizona, USA]
2001 – 2006

- Designed and taught technology integration courses to preservice teachers.
- Conducted original research

Experience continued

Computer Science Department Chair / Teacher
Seoul International School
[Seoul, South Korea]
1999 – 2001

- Coordinated and taught computer science instruction throughout the department.
- C++, Visual Basic, Intro to Computers.

Spanish Teacher / Class IX Dean
Waterford School
[Sandy, Utah]
1997 – 1999

- Coordinated and taught computer science instruction throughout the department
- C++, Visual Basic, Intro to Computers
- Worked with parents and administration to manage Class IX student behaviors

Research Focus

Scaffolding in authentic learning environments including inquiry-based, maker spaces and problem-based learning

Competencies

- Software programming: C++, Perl, Visual Basic, Java, Toolbook
- Instructional design & development
- Multimedia: video, audio, graphics
- Leadership & mentoring
- PreK-12 design & instruction
- Problem-based learning methods

Awards

- Outstanding Performance Award – 2022 Dept. of Defense Ed. Activity (DoDEA)
- Outstanding Paper Award: Full Paper Category – 2018

  See Larson et al. (2018) listed below

Certifications

- Colorado State Teaching License K-12: Spanish / Linguistically Diverse Education
- Arizona State Teaching License 6-12: Spanish / Bilingual Education PreK-12

Volunteer Experience

- *Board of Directors* – The Rusty Berg Foundation – Arizona, USA – 2019-present
- *Board Member*: Education Specialist – Foster Source – Denver, Colorado, USA – 2016-2020
- *Foster Parent* – Denver, Colorado & Queen Creek, Arizona, USA – 2013-1017
- *President* – LDS Women's Relief Society – Queen Creek, Arizona, USA – 2007-2010
- State of Utah Days of '47 Organizing Committee Member – 1998 & 1999

International Experience

<u>Residence</u>

- USA, UK, Canada, Spain, Saudi Arabia, Hong Kong, UAE (Dubai), South Korea

<u>Languages</u>

- English, Spanish, French, Korean

Publications & Presentations

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engineering course. Paper presented at the Hong Kong Association for Educational Communications and Technology International Conference, Hong Kong, China.

Larson, J. S., Farnsworth, K., Folkestad, L.S., Khodadadi Tirkolaei, H., Glazewski, K., & Savenye, W. (2018). Using problem-based learning to enable application of foundation engineering knowledge in a real-world problem. Proceedings of the 2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE) (pp.500-506). Wollongong, Australia: University of Wollongong.

Farnsworth, K. & Winters, S. (2018, October). Scaffolding middle-school students in a PBL makerspaces unit: Scaffolding means vs scaffolding intentions. Paper presented at the annual meeting of the Association for Educational Communications and Technology, Kansas City, Kansas, USA.

Farnsworth, K., & Brush, T. (2017, March). Scaffolding problem-based learning: What works for lowachieving learners? Paper presented at the annual Instructional Systems Technology Conference, Bloomington, Indiana USA.

Farnsworth, K., Llama, G., Na, Y., & Clark, D. (2004, October) Developing online problem-based instruction for bilingual learners: Technology opening diverse opportunities for science (TODOS)
project. Paper presented at the annual meeting of the Association for Educational Communications and Technology, Chicago, Illinois, USA.

Brush, T., Glazewski, K., Rutowski, K., Berg [Farnsworth], K., Stromfors, C., Hernandez Van-Nest, M., Stock, L. & Sutton, J. (2003) Integrating technology in a fieldbased teacher training program: The PT3@ASU project. *Educational Technology Research and Development*, *51*(1), 57-72.

Rutowski, K., Berg [Farnsworth], K., Krumwiede, L., Mansfield, J., Smith, P., Stromfors, C., Sutton, J., Igoe, A.R., Glazewski, K., & Brush, T. (2003). The impact of integrated field-based technology courses on preservice teachers' beliefs, competence, and practice. Paper presented at the annual meeting of the Society for Information Technology and Teacher Education, Santa Fe, New Mexico, USA.

Glazewski, K., Berg [Farnsworth], K., & Brush, T. (2002). Integrating technology into preservice teacher education: Comparing a field-based model with a traditional approach. Paper presented at the annual meeting of the Society for Information Technology and Teacher Education, Nashville, Tennessee, USA.