PEER LEARNING ASSISTANTS FACILITATE STUDENT LEARNING AND ENGAGEMENT THROUGH INTERACTIVE DISCOURSE

by

BRITTNEY ANNE FERRARI

(Under the Direction of Julie Kittleson)

ABSTRACT

Effective active learning supports student engagement in generative learning behaviors, often through collaborative group work. Although collaborative learning has many benefits, it can be difficult for individual instructors to prompt knowledge building discourse in large enrollment courses. Peer Learning Assistants (PLAs) can provide the instructional assistance needed to facilitate student engagement in active learning. This research explored how PLAs supported learning while students worked collaboratively in groups in an introductory biology course. I used a peer-led interactive discourse framework to investigate how PLAs facilitated student engagement in knowledge building discourse. This framework was informed by the ICAP modes of engagement (Interactive, Constructive, Active, Passive), which posits that students' cognitive engagement in a learning task is exhibited through their overt behaviors. Using discourse analysis to analyze audio recordings of PLA-student interactions as student worked collaboratively in groups, I described PLA practices and student actions that were pertinent to student learning. Then, I applied the ICAP framework to characterize each PLA-student interaction as Interactive, Constructive, Active, or Passive based on the groups' actions. All interactions were also given an Interaction Quality Score to quantify the quality of student participation in the interaction. I compared the ICAP characterizations and Interaction Quality Scores of PLA-student interactions between groups to investigate how student participation and group dynamics mediated student performance. I describe four main conclusions: 1. Students were less engaged in generative learning actions when PLAs used informing and mediating practices; 2. Students engaged in generative learning actions when interacting with PLAs that utilized probing and guiding practices; 3. Group dynamics influenced the nature of PLA-student interactions, such that not all students participated equally; and, 4. The nature of student engagement in PLA-student interactions may mediate student performance. I found that student participation in Interactive interactions was the most supportive of student performance, and students who engaged with the PLA during these interactions performed better than their less engaged peers. This research offers implications for PLA pedagogy training and instructor decision-making regarding effective implementation of active learning to support student engagement in knowledge building discourse.

INDEX WORDS: Peer Learning, Learning Assistants, Active Learning, College Science Education, Discourse, Collaborative Learning

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DEDICATION

This dissertation is dedicated to Savannah. I hope you have big dreams and the fearlessness to chase them.

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I spent the better part of the past year sitting on the floor. Watching Savannah struggle to lift her head during tummy time and now trying to catch her before she falls, as her little feet move faster than her body is ready for. The days were long, and it often felt like my research would never get done. But here we are, here I am, with a faculty position before I even graduated. Those who know me know that my persistence is tediously limitless, but truthfully, I couldn’t have made it here on my own. The people who’ve helped and supported me through this, they’ve got me surrounded for a mile or two and I’d like to spend some time thanking them.

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CHAPTER 1

INTRODUCTION

1.1 Why Peer Assisted Learning?

From working as an undergraduate peer tutor to a graduate teaching assistant, throughout my academic career I have observed students memorizing information and obsessing over getting the “right answer” with little concern for building their understanding of science concepts. I care deeply about student learning and how students make sense of scientific knowledge, but I believe students need to learn *how to learn*. My hope is that they learn they have to actively engage in with course material in order to build knowledge. Engagement might include applying scientific practices like predicting and reasoning, thinking about the concepts they are learning, and reflecting on their understanding of them. Ultimately, I want students to see science as a way of knowing and understanding the world around them, not a set of facts to be memorized.

As an undergraduate biology student, I personally did not want to participate in an active learning classroom. I preferred to sit in a lecture and absorb the information transmitted from the professor while I scribbled my notes, trying to keep up. I had always done well in classes and did not believe I needed any help. And I wasn’t wrong; if I went to class, took notes, read the textbook and studied, I did well. I attributed my success to my love of learning; I liked to know things, and often I judged my knowledge on my ability to explain concepts to others.

I applied for a job on campus with the Supplemental Instruction (SI) program as a peer tutor, and I soon found myself leading group tutoring sessions for an introductory biology course. In these sessions, I gave short interactive lectures, posed a lot of questions, and facilitated group activities for approximately 10-20 students that voluntarily attended. I found that I was really good at breaking down complex concepts for students and collaboratively reconstructing them. Students would often lament that their professor was too smart to explain things to them, and SI helped because they could learn from me and their peers. The idea that peers could explain things differently (and in some cases, more effectively) than professors is what I began referring to as "student speak." It is something I have thought about often in relation to the "curse of knowledge," such that maybe professors are too well versed in their subject matter to explain the fundamentals of it to students. I wondered, how can novice peer teachers be more successful (in some cases) at explaining concepts and supporting student learning than expert college instructors? This question has stuck with me for years.

As a graduate student, I taught an introductory biology laboratory course that used a collaborative, inquiry-guided approach to learning, in which students were the principal investigators and TAs were the facilitators. My observation was that students do not appreciate this approach and were often more concerned with getting the "right" answer than taking the time to think about the question. There seemed to be a disregard for the *process* of learning and priority on the *product*. I found this disappointing. Many students in these labs were pre-health majors, so as the future doctors of America, I wanted them to be able to problem-solve, reason, and think independently. While I made every effort to help students develop these skills and the inquiry labs provided a suitable setting to practice them, I worried that the associated lecture course was a more traditional, passive learning environment much like the ones I sat through in college. I began to wonder if these active learning practices we were developing in lab would be nurtured or squashed once the students left my lab.

I was excited to learn that the Division of Biological Sciences had established a Peer Learning Assistant (PLA) program in their introductory biology courses. PLAs are students who successfully completed a course and return to provide additional instructional assistance in support of active learning initiatives. Given my experience with SI, I was quick to get involved in a research project that examined whether PLAs effectively supported student learning during different class activities (Ferrari et al., 2023). Around the same time, I started my PhD in science education and learned about theoretical perspectives I had never heard of before. I knew I wanted to focus my dissertation research on peer-assisted learning but did not really know a lot about educational research.

Upon diving into the literature, I realized most studies that investigated peer-assisted learning came from practitioner journals that almost exclusively used quantitative research. They showed evidence of the positive impact of peer-assisted learning on student performance, but the discussion of theory was lacking. Many cited social constructivism (Vygotsky, 1978) without using it to explain what was happening. I wanted to know *why* peer learning works and *how*. In what ways do peers help other students learn – could it be related to "student speak" or was the process more complex? Was there a more useful theoretical framework for helping us understand how students can learn from one another?

My experiences with peer learning bolstered my belief that it is a successful avenue for achieving deep learning and cultivating effective learning strategies. Peer teachers like PLAs help support active learning by bringing student thinking to the forefront of the learning experience and using it to engage students in knowledge building discourse. While I had my own ideas about what makes an effective peer teacher, I wanted to investigate what PLAs were actually doing in their interactions with students to facilitate their learning. More so, I wanted to develop a set of “best practices” that PLAs could use to guide their interactions with students. My background in science instilled a sense of pragmatism, so I was determined to conduct research that offered practical ways to improve college science instruction using peer-assisted learning.

1.2 Problem Statement

Concerns regarding the future of STEM education in the United States have prompted numerous initiatives aimed at addressing the declining number of college students entering and persisting in the STEM disciplines, which was reported by the President’s Council of Advisors on Science and Technology (PCAST, 2012). However, as class sizes grow, so does the ratio of students to instructor. This amplifies challenges already present in traditionally large, lecture-based introductory science courses, which serve as barriers to students rather than a gateway to the major (Tai et al., 2005). Without additional instructional support to facilitate active learning, these courses may become impediments for students pursuing science majors as many cite uninspiring and non-inclusive classroom environments as the main reason for leaving STEM majors (PCAST, 2012).

To address these concerns, instructors have sought to transform their courses from passive, traditional instruction to student-centered instruction by incorporating reformed teaching approaches (Froyd, 2008; Wood, 2009). One approach that many higher education institutions have used to achieve such transformations is the implementation of Peer Learning Assistant (PLA) programs in STEM courses across various disciplines. PLAs are undergraduate students who recently successfully completed a course and subsequently return to provide additional instructional support (Otero et al., 2006). They are trained to support student learning by using evidence-based teaching strategies such as guided questioning, evidential reasoning, and formative assessment to promote active engagement among students (Blackwell et al., 2017; Philipp et al., 2016a).

PLAs help support active learning in large classrooms because they provide the assistance needed for facilitating group work and fostering discussion (Otero et al., 2006), thereby redirecting the traditional linear transmission of information into a multidirectional flow of information between students, PLAs, and the instructor. In these environments, students can meaningfully engage with course material and actively construct knowledge with peers (Ebert-May et al., 1997; Knight & Wood, 2005; Otero et al., 2006). There is evidence that students in PLA-supported science courses perform better on exams and earn higher overall grades than students in traditional science courses (e.g., Chapín et al., 2014; Chasteen et al., 2011; Philipp et al., 2016a; Pollock, 2006; White et al., 2016). Students in PLA-supported courses also report having more positive attitudes towards STEM (Talbot et al., 2015) and are more likely to enroll in subsequent science courses compared to those not supported by PLAs (Philipp et al., 2016b).

While numerous studies have documented if PLAs help students learn, only a few have investigated the ways in which PLAs might support student learning. For example, Talbot et al. (2015) used social network analysis to illustrate how PLAs were the central figures in the classroom and fostered interactions between students. Knight et al. (2015) found that PLAs' different questioning prompts influenced the quality and quantity of students' discussions during clicker questions. These studies highlight the important role PLAs play in the classroom as their actions promote active learning and student engagement. Thompson et al. (2020) recently developed a tool that outlines PLA actions during their interactions with students. Although it has not been applied yet to understand the impact of those actions, it could provide helpful insights on which PLA actions are most supportive of student learning.

Studies that assessed if PLAs help students learn make claims regarding the PLAs' positive impact on student learning by using student performance in PLA-supported courses as a proxy for learning. While performance is a useful and convenient way to evaluate student learning, it is not necessarily indicative of students' level of understanding. Additionally, much of the research investigating the impact of PLAs on student learning in large, undergraduate science courses discuss PLAs in the context of active learning and social constructivism (e.g., Vygotsky, 1978). However, learning gains are assessed through concept inventories and final exams. Again, these metrics provide easily quantifiable ways to assess student performance, but do not provide much insight as to the ways in which students build understanding of course concepts. This is not to say that student performance is not an adequate method for evaluating student learning, or that PLAs cannot facilitate socially constructed knowledge and active learning, but additional evidence is needed to explore the ways in which PLAs support student knowledge construction and thus, their performance.

Active learning is often a challenging term to define, as it has become somewhat of a buzzword in education and can be rather ambiguous (Chi & Wylie, 2014). There are numerous initiatives in science education to transform classrooms into more student-centered, active learning environments (e.g., American Association for the Advancement of Science [AAAS], 2009). In these spaces, students are making sense of information, grappling with data, practicing self-assessment and reflection, and transferring knowledge to reach learning goals aligned with building understanding (National Research Council [NRC], 2000). Other approaches to active learning include problem-solving and activities that promote higher-order cognitive processing. Problem-solving often requires students to activate prior knowledge in order to attend to the deep structure of the problem and in some ways can serve as formative assessment by revealing knowledge gaps (Kapur, 2016). Instructors can engage students in higher-order cognitive thinking through numerous activities including evidence-based reasoning, data analysis, and problem-solving. What sets more effective active learning activities apart from those less effective is how well they engage students in constructive behaviors (Andrews et al., 2011; Chi & Wylie, 2014).

Evaluating students' engagement in cognitive tasks can be a challenge, as these tasks involve inherently internal processes. However, Chi and Wylie (2014) developed a framework that defines student active engagement in terms of overt behaviors that can be observed. Within this framework there are four different modes of cognitive engagement – *Interactive, Constructive*, *Active*, and *Passive* (ICAP) – that reflect a hierarchy of learning such that the *Interactive* mode of engagement is most supportive of learning while the *Passive* mode is the least. In the *Interactive* mode, students collaborate through dialogue to co-construct their understanding. In the *Constructive* mode, students independently engage in behaviors that generate new ideas. Students engaged in the *Active* mode manipulate information provided to them without producing anything new. Students in the *Passive* mode receive information without taking any other actions (Chi & Wylie, 2014). Thus, the ICAP framework offers an approach to investigate students' level of cognitive engagement and understanding by observing their actions while completing a learning task.

The ICAP framework has been applied in numerous studies to compare learning outcomes for the different modes of engagement and offer relevant insights for instructors using active learning approaches (e.g., Morris & Chi, 2020; El-Mansy et al., 2022; Wiggins et al., 2017). While many of these studies focused their investigation on the generative modes (*Interactive* and *Constructive*), only a few have done so within the context of peer learning (e.g., Henderson, 2019; Leupen et al., 2020). However, no studies have specifically considered the role of peer teachers, such as PLAs, within the ICAP framework. As college science instructors seek to transform their courses into student-centered, active learning spaces with the assistance of PLAs, it is important to understand how PLAs can most effectively engage students in generative modes of learning. Furthermore, with the growing implementation of collaborative learning, exploring how PLAs facilitate student participation in group work is also of interest.

1.3 Statement of Purpose

Active learning is an essential part of undergraduate STEM education, as it creates opportunities for students to build their understanding of complex concepts. However, active learning is challenging to implement in large, introductory science courses without additional instructional support. As the STEM field continues to grow, there will be a continuing need for additional instructional support in the classroom and PLAs offer a cost-efficient way to provide more instruction, reduce the student to teacher ratio, and facilitate active learning among students (Goldschmid & Goldschmid, 1976). However, little is known about the ways in which PLAs engage students in active learning activities, such as collaborative group work, that promote knowledge building discourse. The ICAP framework presents a lens through which student behaviors can be evaluated to determine if students are engaged generatively while collaborating with peers. In particular, it is important to consider how PLAs facilitate active learning in an introductory college science course because most students in these classes are freshman and sophomores and likely have limited experience engaging in knowledge building discourse. Therefore, it is important to understand *how* PLAs support student learning and participation in collaborative group work to ensure that PLAs are implemented effectively in introductory science courses.

The purpose of this study is to understand *how* Peer Learning Assistants support student learning and engagement in collaborative group work. Moreover, this study aims to provide insights on how peer-assisted learning may be implemented more effectively in introductory college science classrooms. In this study, student learning is conceptualized as building understanding (i.e., knowledge construction) and viewed through the ICAP lens, and student performance is also considered. This study seeks to understand how Peer Learning Assistants support student engagement in generative modes of learning while working collaboratively with peers in college introductory biology courses. I use qualitative inquiry, specifically discourse analysis, to explore the ways in which PLAs facilitate student knowledge building using the ICAP modes of cognitive engagement as a conceptual lens. In relation to these findings, I examine student performance and group dynamics to consider how student participation in group interactions with PLAs mediates student performance. Lastly, I discuss how PLAs can guide interactions with students towards generative learning goals and prompt participation among group members during their interactions.

1.4 Research Questions

This research was guided by the following questions:

RQ1. In what ways do PLA practices facilitate student knowledge construction while students work collaboratively in groups?

RQ2. How do student engagement and group dynamics during PLA interactions mediate performance?

CHAPTER 2

REVIEW OF RELEVANT LITERATURE

The launch of Sputnik in the 1950s spurred calls for science education reform in the United States because it served as a signal of the country's failed education system (Bracey, 2007). Around this time, professors of education were promoting pedagogical progressivism and student-centered classrooms focused on learning through experience, although the sentiment was rarely enacted in universities or K-12 schools (Reese, 2001). The competing ideology was administrative progressivism, which ultimately prevailed and resulted in teacher-centered classrooms focused on meeting standards (Labaree, 2005). In recent years, calls for pedagogical progressivism have been reignited, causing a shift towards more reform-based teaching practices that incorporate student-centered learning and activities. However, concerns regarding the future of STEM education remain as these practices can be difficult to implement effectively.

According to the report *Engaging to Excel* by the President's Council of Advisors on Science and Technology (PCAST), the proportion of students earning degrees in STEM is falling among all college graduates. Moreover, less than 40% of students entering college with the intent to major in STEM complete a STEM degree (PCAST, 2012). Reasons for leaving these majors regularly reference uninspiring introductory courses due to poor teaching methods and lack of an inclusive learning environment (PCAST, 2012). This presents issues not only for the future of STEM professionals, but also for the United States economy and STEM literacy of the American public. Therefore, two key recommendations of the PCAST report are to stimulate extensive implementation of evidence-based teaching practices and to expand the use of scientific research courses across STEM disciplines (PCAST, 2012). These recommendations appear to address two aims of science education that have existed since the middle of the 20th century. The first is to cultivate students' knowledge of scientific concepts, theories, and facts. The second is to develop their awareness and understanding of the process of science (Glass, 1967).

College science courses largely fall into two fields, the life sciences (namely biology) and the physical sciences (physics, chemistry, and engineering). The purpose of this review is to briefly characterize the landscape of undergraduate biology teaching reform efforts, discuss the role of active learning in undergraduate science courses, and explore peer-assisted learning as an approach to supportive active learning in college science courses.

2.1 The Landscape of Undergraduate Introductory Biology

Reform-based Teaching in College Biology

In 2019, the American Association for Advancement of Science (AAAS) released a document, *Levers for Change: An Assessment of Progress on Changing STEM Instruction*, which reported on the implementation of reform-based teaching efforts across STEM disciplines. This report was in response to evidence that most students do not experience student-centered instruction in college science, despite evidence showing positive impact of pedagogical approaches that foster active learning and collaboration among students in these settings (AAAS, 2019). The disconnect appears to be from a lack of effective use, rather than lack of awareness of evidence-based reformed teaching approaches. *Levers for Change* outlined the current state of major reform efforts for teaching across undergraduate STEM disciplines and described the "levers" that instigated these changes.

In the biological sciences, the use of evidence-based reforms has increased over time, but many instructors still cite lecturing as their most common teaching method, suggesting that instructors are not using reformed teaching approaches extensively or effectively (AAAS, 2019). Likewise, there is widespread recognition that students in life sciences should be engaged in scientific practices, but data suggest enactment of this pedagogical approach is low. The publication of *Vision and Change in Undergraduate Biology Education* has been the most considerable "lever" influencing life science education. *Vision and Change* created a framework for undergraduate core curriculum and competencies, as well as a guide for student-centered instruction and professional development to support such an instructional approach (AAAS, 2009). The impact of this publication has yet to be fully realized, but it has provided the life science community with a pathway for undergraduate programs to identify learning goals and design courses to better address those goals through student-centered instruction and evidence-based teaching reforms (AAAS, 2019).

Vision and Change identified five core concepts and six competencies for students to learn in the biological sciences. The concepts include evolution, structure and function, information flow, exchange and storage, transformation of energy and matter, and systems. The competencies include applying the process of science, using quantitative reasoning, utilizing modeling and simulation, recognizing the interdisciplinary nature of science, communicating and collaborating with others, and appreciating the relationship between science and society (AAAS, 2009).

Vision and Change also recommended biology courses transition to student-centered instruction by using the concept of scientific thinking to revise courses. This stems from the recognition that students construct new knowledge into their pre-existing knowledge. Therefore, student thinking should be at the forefront of instruction by using formative assessment to gauge and frequent feedback to support students as they develop their understanding of course concepts. The goals of student-centered instruction are such that students will develop life-long science competencies, engage in research experiences to explore the natural world, and actively participate and collaborate with others. *Vision and Change* highlighted pedagogical approaches to achieve those objectives including integrating scientific practices into all biology courses, covering fewer concepts more in-depth and making them relevant to real-world issues, and stimulating curiosity for learning about biology by showing scientists' passion, engagement, and interdisciplinary collaboration (AAAS, 2009).

More broadly, the National Research Council (NRC, 2012) recommended that students in undergraduate science courses be engaged in the process of science to learn accepted practices of the science community like problem-solving, evidential reasoning, and critical thinking. Ultimately, learning science should reflect the process of science so that students understand how scientific practices are used to construct scientific knowledge (NRC, 2012). Moreover, introductory science courses should offer opportunities to teach students how to become more successful, intentional learners. Student-centered instructional approaches that make student thinking explicit and promote reflection on that thinking are useful for developing students' metacognition (NRC, 2000). This learning strategy has documented benefits for students and may be an important skill to navigate traditionally challenging college science courses and to create sustainable learning strategies.

As discussed, teaching reforms across university-level STEM courses have centered on course transformation from passive traditional instruction to student-centered instruction (Froyd, 2008; Wood, 2009). This shift creates an active learning environment that redirects the linear transmission of information from teacher to student into a multidirectional flow of information between students, their peers, and the instructor (Otero et al., 2006). Active learning classrooms encourage student engagement with course material and with peers, thereby fostering active knowledge construction rather than passive information absorption (Ebert-May, Brewer, & Allred, 1997). Various pedagogical approaches have been implemented to cultivate these types of environments, but one that shows considerable promise is peer-assisted learning, in which undergraduate students who have recently successfully completed a course return to assist student learning in that course by providing additional instructional support in the classroom (Lockspeiser et al., 2008).

To achieve this course transformation and promote active learning, many universities have implemented peer teaching programs. These programs either refer to the peer teachers as [Peer] Learning Assistants (PLAs/LAs) or Undergraduate Teaching Assistants (UTAs). For simplification, all peer teachers will be referred to as PLAs in this review. PLA programs support interactive learning environments by facilitating student engagement in class activities. In these environments, students learn course material through collaborative activities that put student thinking at the forefront and promote collective sense-making with peers (Ebert-May, Brewer, & Allred, 1997; Otero et al., 2006). PLAs provide much needed additional instructional support that can be leveraged to implement more student-centered pedagogy in large lecture courses that may otherwise be unattainable.

2.2 Theoretical Underpinnings of Peer-assisted Learning

Constructivism

Before delving into the social perspectives of learning, I think it is important to consider the ideas presented by Piaget's (2003) theory of knowledge construction. Piaget theorized that knowledge is acquired through constructivism such that pre-existing ideas impact future learning through a series of assimilations and accommodations (2003). Students enter the classroom with prior knowledge based on their personal experiences with phenomena in their daily lives. Piaget described this prior knowledge as spontaneous, as it is often inaccurate or incomplete. Through instruction, students are confronted with new information that either supports or contradicts that knowledge. When students are introduced to information that appears to align with their current conception, they will assimilate it by organizing it into their current scheme. However, when presented with information that conflicts with their understanding, an accommodation is made by integrating it, which changes their conception to create a more properly functioning scheme. By filling in the gaps and addressing the errors in their understanding, students gradually adjust their spontaneous conceptions into more scientific ones (Piaget, 2003).

Piaget (2003) argued that the balancing act of assimilation and accommodation of new information with respect to previous experiences is how knowledge is constructed. Moreover, the processes of assimilation and accommodation are self-regulating and integrative, such that students engage in them as they interact with and receive feedback from their environment (Fosnot & Perry, 2005). PLAs can play a role in this process by providing the feedback necessary to encourage students to reflect on why the new information does not fit within their current conception. Through their iterative discussions, PLAs provide clarification and guidance as students try to make sense of the new, conflicting information.

While Piaget was known as a cognitive-developmental psychologist and thus a proponent of cognitive constructivism, he also discussed the benefits of students learning from peers. For example, Piaget conceptualized peer interactions as a means for providing young learners with personalized constructive feedback. Murray (1968) explains that Piaget believed that peer interaction fosters development by creating critical cognitive conflicts, such that a child is presented with a contradiction between what she believes and what the world, or her peer, is telling her. The child must confront this contradiction, question her beliefs, and consider alternative explanations. In peer-assisted learning, the PLA serves as the source of cognitive conflict and can serve as a catalyst for change. During their interaction, the student becomes aware of opposing viewpoints, examines his or her own interpretation, and must justify it by communicating it clearly to another student. Thus, according to Piaget, children gain both cognitive and social benefits from peer-assisted learning (Damon, 1984).

A similar perspective on the effectiveness of peer-assisted learning stems from Sullivan (1953) and his ideas on the "co-construction" of ideas that occur during peer learning interactions. Sullivan (1953) posited that student peers view one another as equals with a shared goal, and therefore are not compelled to copy or adopt the other's competence. Instead, they collaborate through dialogue to share ideas, seek consensus, discuss new insights, and mutually generate shared knowledge. These behaviors are consistent with cognitive outcomes of the interactive knowledge change processes described in Chi and Wylie's ICAP framework (2014), which posits that the co-generation of knowledge between peers leads to the deepest level of understanding. Collaboration is also an important social skill for students to develop, as it only succeeds in an environment of mutual respect (Piaget, 1965). Moreover, collaboration fosters an active exchange of ideas between peers and encourages learning through interactive discovery. In agreement with Piaget, Sullivan (1953) links the ability for students to freely share their thoughts and listen to another perspective with their development of empathy, kindness, and justice. This suggests that the cognitive development of one's own understanding is supported by social interactions with peers.

Prior or spontaneous knowledge, even that which is inaccurate, is necessary for learning because it is the foundation upon which students construct new, more scientifically accurate knowledge. Students' prior knowledge often includes misconceptions or gaps, and PLAs must be able to recognize them in their discussions with students by using formative assessment. PLAs are trained to ask students guiding questions rather than just provide them with answers, which encourages students to reflect on and explain their thinking (Otero et al., 2010). Through discussions with students, PLAs may be able to diagnose misunderstandings by the questions that students ask and how students respond to the PLAs' reflective questioning. Through this iterative cycle of questioning and explaining, PLAs can start to help students identify what they do not know or understand. A critical aspect of learning is identifying the limit of one's knowledge and students are unlikely to explore those limits without prompting by a peer, specifically a more knowledgeable one that knows where the gaps, inaccuracies, and misconceptions are usually found. Once those gaps or errors in thinking are identified, PLAs can guide the transformation of students' knowledge from spontaneous to more scientific by helping them make sense of new information so that it is integrated appropriately.

Sociocultural Perspective

Views regarding the importance of peer interaction in student learning is brought to the forefront in Vygotsky's sociocultural theory of learning (1978), which posits that students internalize the words and actions of others and adapt their own behavior and language as a result of their interactions. This theory is distinct from other cognitive development theories because it asserts that learning cannot be separated from the social context, such that community plays a central role in the "meaning making" of information (Driver et al., 1994). Because interactions with students and PLAs occur in the classroom, learning cannot be separated from the social context, such that community and culture plays a central role in a student making sense of information presented in that classroom.

A central concept of Vygotsky's is that collaborative construction of knowledge is often guided by a more knowledgeable other (MKO). The MKO refers to a more capable person with a more complete and accurate understanding of the material that can facilitate a student's transition to a higher cognitive level of understanding (Vygotsky, 1978). In peer-assisted learning, the PLA serves as the MKO. Another key feature of this perspective is the zone of proximal development (ZPD), which represents the distance between a student's level of potential development and their actual development (Vygotsky, 1978). Put simply, it is the area between what a student can learn independently and what a student can only learn with the guidance of another (the MKO). To move through the ZPD to a higher level of understanding, the student needs to be challenged but also supported. Often, this support comes from scaffolding by the MKO. PLAs engage in scaffolding through their recursive discourse with students. Through this process, students constantly refine their conception and move to a higher level of understanding and learning. The more that students learn, the more they develop, meaning that they are better positioned to learn more material because the actions they have developed through interactions with the MKO support their construction of new knowledge.

Similar to Piaget, Vygotsky also theorized that students hold pseudo-concepts about the content they are learning. These pseudo-concepts are influenced by students' previous experiences and interactions with the natural world. They often are missing important details and connections, resulting in an incomplete understanding of the content (Fosnot & Perry, 2005). In school, these conceptions are confronted by information presented from others such as an instructor or peer. However, with time and instruction, these pseudo-conceptions can slowly shift to more scientific conceptions. Through discussion with MKOs, misconceptions or inaccuracies observed in pseudo-concepts can be identified and corrected. This demonstrates a critical aspect of Vygotsky's theory, such that speech and language are necessary for development as students use them to make sense of information. However, a student may not be able to integrate new information and transition pseudo-concepts to scientific ones without the assistance of an MKO if understanding the concept is beyond their zone of proximal development (Vygotsky, 1978).

In addition to addressing pseudo-concepts, the interactions between PLAs and students are also valuable as students build foundational knowledge, a necessary step before students can develop higher order cognitive skills. As novices, students often require assistance understanding, contextualizing, and organizing facts in order to develop a conceptual framework (NRC, 2000). As experts, or MKOs, PLAs can help students assemble such a framework because they have already done this successfully. The organized schemas that experts develop allow them to recognize patterns when solving problems. Therefore, PLAs can also help students integrate newly presented information by connecting it to other concepts they have learned. Instructional scaffolding, including prompting, encouraging, and questioning, is one method peers can use to assist other students to construct knowledge (Chi & Wylie, 2014). Once students have built foundational knowledge through their interactions with peers, they are better positioned to develop skills that are needed for higher order cognitive processes and problem-solving.

As a more knowledgeable other, PLAs not only support students' development, but also their enculturation into the scientific community. The central epistemology within this community is that science is viewed as a way of knowing. However, many students are not familiar with this epistemology, so part of the PLA's role is to introduce students to this way of thinking and the related discourse. PLAs may attempt to incorporate scientific thinking in their discussions with students and implicitly engage them in practices that reflect the "process of science," such as problem solving, critical thinking, evidence-based reasoning, and questioning

(NRC, 2000). As PLAs model and engage in these practices with students, students learn how knowledge is constructed in science. In this way, PLAs help to establish a community of practice (Wenger, 1998) where students can observe how to be successful science learners, internalize those behaviors, and adopt them as a result of their interactions with PLAs.

Through social activity, such as peer interaction, students actively observe others and internalize the behaviors they see (Vygotsky, 1978). By interacting with more knowledgeable peers who are using culturally accepted scientific practices like reasoning, students will learn to take on similar actions as a result of their continued interaction. Moreover, in addition to modeling practices of the scientific community, PLAs also situate students to the undergraduate science classroom community and its associated activities. In this space, students learn the cultural norms, expectations, and actions of the classroom context through their interactions with PLAs (Thompson et al., 2020). Thus, learning occurs with the social activity itself (Reynolds et al., 1996). Consequently, the sociocultural context of a PLA supported classroom cannot be understated, as the collaborative, student-centered environment that they facilitate is essential for student learning.

Another important consideration of PLAs' influence on the development of students is that they represent a "model science student." Students view PLAs as a peer that has successfully completed the course and understands both the material and challenges that students encounter in that course. Therefore, students not only learn course content from peers but also have the opportunity to closely observe a peer's model performance when completing academic tasks (Conrad, 1974). Additionally, because near peer teachers have recently completed the course they are supporting, they are able to explain course concepts in familiar terms to students and are aware of the misconceptions related with those concepts (Bulte et al., 2007). This is supported by a concept called "social and cognitive congruence," which suggests that students value learning from near-peers because they have similar, recent experiences with course content and understand the challenges associated with it (Lockspeiser et al., 2008). As socially congruent, students recognize that PLAs are similar in age, experience, and social roles. As cognitively congruent, PLAs can explain concepts to their peers in an accessible way because their level of understanding is similar. In addition, because students are working with a peer rather than a teacher, there is less of a perceived stigma for giving a wrong answer. With this perspective, students value the assistance provided by PLAs and may try to adopt the practices, actions, and language of the PLAs because they perceive them to be successful and achievable.

Social Constructivism

The social constructivist theory of learning builds on the ideas of constructivism while incorporating the context of social interactions and cultural activities. While these two perspectives of learning are often viewed on opposite ends of a spectrum, one described as an individual cognitive process and the other a sociocultural experience, Cobb (1994) argued that the two theories can actually complement one another. A key feature of both perspectives is the role of activity in knowledge construction, either individual cognitive activity or social activity. However, knowledge construction and learning may be better conceptualized by combining these notions, such that cognitive activity is stimulated by and develops through social interactions (Cobb, 1994). By considering both perspectives, social constructivism explains that information may be learned from others or individually, but without a social and cultural context, we cannot make sense of that information. In short, learning requires both cognition and experience.

Driver et al. (1994) also states that concepts to be learned cannot be discovered or understood on one's own, such that making sense and meaning of these concepts requires the assistance of another. This is particularly true in science, as scientific concepts and entities may be "taken for granted" within the scientific community but are largely unknowable or undiscoverable to the novice science student acting alone. While these scientific entities have been socially constructed and communicated within the community, those outside of it cannot see the world through the same scientific lens. One must be initiated into the scientific culture, exposed to the epistemology, discourse, and practices that are applied to not only discover scientific ideas but to make meaning of them (Driver et al., 1994). PLAs demonstrate to students how to view science as a way of knowing and utilize cultural discourse and practices to make meaning of new information. They facilitate students' adoption of such practices and encourage interaction among peers so that students work together to make sense of information, co-construct scientific knowledge, and be confident in their shared understanding of it.

Cobb and Yackel (1996) proffered their version of social constructivism that they referred to as the emergent perspective. According to this perspective, "learning is a constructive process that occurs while participating in and contributing to the practices" of the classroom (Cobb & Yackel, 1996), where participating establishes the conditions for the possibility of learning. In the emergent approach, the teacher coordinates their activities with the students to proactively support the students' individual constructions and evolution of classroom practices, so students are better positioned to participate effectively in cultural practices outside of the classroom (Cobb & Yackel, 1996). This is similar to the role of the PLA, as their supportive actions are in response to students' individual needs and questions, thereby engaging in mutual adaptation with students as they work together to make meaning of course information. The emergent perspective as an approach to understanding peer learning is unique in that it focuses on students' communal activity, rather than solely their individual actions, as an explicit objective of analysis (Cobb & Yackel, 1996). In other words, learning is not separate from the students' interaction, but a result of it.

PLAs can help transform classrooms into more student-centered environments that support engagement and collaborative learning. This is supported by multiple theories of learning that act simultaneously in the classroom. Constructivism is present as students use their prior knowledge to construct new knowledge through their discussions with peers and PLAs (Piaget, 2003). PLAs represent more knowledgeable others that scaffold students' knowledge construction and development of conceptual frameworks (Vygotsky, 1978). PLAs model skills such as metacognition, reasoning, and problem-solving, and students learn to adopt these necessary cognitive skills for learning. Through their social interactions with peers and PLAs, students learn the culturally accepted practices that the scientific community observes to generate scientific knowledge (Brown et al., 1989; Cobb, 1994). Consequently, the sociocultural context of a PLA supported classroom cannot be understated, as the collaborative, student-centered environment that they facilitate is essential for student meaning-making, knowledge construction and learning.

2.3 Conceptual Underpinnings of Peer-assisted Learning

Active Learning and Collaborative Discourse

Active learning is often a challenging term to define, as it has become somewhat of a buzzword in education but can be rather ambiguous (Chi & Wylie, 2014). Most often, it is used to describe learning environments that are student-centered, where students are cognitively engaged in activity designed to further enhance their understanding of course material. Active learning can take on many forms, such as students grappling with data, practicing self-assessment, engaging in reflective thinking, and transferring knowledge (National Resource

Council (NRC), 2000). Other approaches to active learning include activities that promote higher-order cognitive processing and problem-solving. These activities often require students to activate prior knowledge in order to attend to the deep structure of the problem and in some ways can serve as formative assessment by revealing knowledge gaps (Kapur, 2016).

There is considerable evidence that active learning strategies improve student success outcomes more so than traditional instructional approaches (NRC, 2012; Freeman et al., 2014). Because of this, educational reform efforts have called for the adoption of evidence-based, active learning strategies to transform STEM classrooms from passive lectures to student-centered learning environments (AAAS, 2019; President's Council of Advisors on Science and Technology (PCAST), 2012). However, large class sizes present challenges to effectively implement active learning instruction that supports students' conceptual learning (Sellami et al., 2017; Tai et al., 2005). Moreover, the way in which active learning strategies are implemented can impact their usefulness, as simply adding active learning to a course without providing opportunities for students to monitor their understanding and address misconceptions is ineffective (Andrews et al., 2011). This suggests that active learning should include constructivist elements to be beneficial for learning.

The effectiveness of active learning is contingent upon students' cognitive engagement with course material in a meaningful way, but it can be challenging to gauge students' cognitive activity during a learning task. To address this concern, Chi (2009) developed a hierarchy of cognitive engagement that relies on students' overt behaviors during a learning task, known as ICAP. Chi (2009) describes ICAP as a theory that describes four different modes of student engagement: *Passive, Active, Constructive,* and *Interactive*. In the passive mode, students receive information but don't do anything with that information. Students in the active mode manipulate the information they receive in some way, such as copying notes or answering questions using provided course material. In the constructive mode, students generate new knowledge by using provided course materials and applying it to synthesize information or make inferences. Lastly, in the interactive mode, two or more students collaborate to co-construct knowledge by building off one another's ideas and questions (Chi & Wylie, 2014).

Associated with each of these modes is an underlying cognitive process, such as activating prior knowledge, integrating information, or inferring new knowledge. Chi (2009) proposed that a knowledge-change process occurs as students engage in the learning task and learn new information. As students receive information in the Passive mode, they only store information. In the Active mode, students may activate prior knowledge relevant to the information they were manipulating. Then, new information can be stored if students link it to their prior knowledge. In the Constructive mode, students generate knowledge that was not provided to them, indicating that they are making inferences in addition to activating prior knowledge and making connections to it. In the Interactive mode, students are making their own inferences and those based on the knowledge shared by a peer, suggesting that new knowledge can be generated that neither could have created on their own. According to Chi (2009), the richness of student knowledge that results from the knowledge-change processes is dependent on the modes students engage in. Therefore, the four modes present as a hierarchy of learning (Table 2.1), such that the Interactive mode enhances learning more than the Constructive mode, which is superior to the Active mode, and the Passive mode is the least effective way to learn (Chi, 2009; Chi & Wylie, 2014).

Table 2.1

Summary of the ICAP framework adapted from Chi & Wylie (2014).

Mode of Engagement	**Interactive**	**Constructive**	**Active**	**Passive**
Learning Behavior	Co-constructing	Generating	Manipulating	Receiving
Knowledge Change Process	Co-infer	Infer	Integrate	Store
Learning Outcomes	Deepest understanding	Deep understanding	Shallow understanding	Minimal understanding
	Active Learning			*Passive Learning*

According to the ICAP framework, the highest levels of learning are thought to occur in the Constructive and Interactive modes where students are most cognitively engaged and generating knowledge. Several studies have demonstrated support for this hypothesis, such that Constructive activities like building concept maps or self-explaining are more beneficial than Active and Passive activities (Coleman et al., 1997; Gobert & Clement, 1999; Menekse et al., 2013). It is also predicted that students engaged in Interactive activities will learn more than Cognitive activities because students are the most engaged as they discuss and consider ideas with peers. Notably, students in an undergraduate biology course who completed in-class activities in a group rather than alone did perform better on higher order exam questions (Linton et al., 2014). Moreover, Wiggins et al. (2017) compared pre- and post-test performance of students engaged in either a Constructive or Interactive activity in an introductory biology course and found a significant benefit for students who participated in the Interactive activity. Similar results were found in an undergraduate engineering course (Menekse & Chi, 2019). These studies support the ICAP prediction that compared to the Constructive mode, Interactive activities are associated with greater learning gains.

What these studies also suggest is that there are implications for designing instruction in accordance with the ICAP framework. For example, Morris and Chi (2020) found that the nature of instructor questioning impacts student learning. Students made more inferences and performed better after lessons in which the teacher asked more Constructive questions compared to Active and Passive questions. In addition, when given more time to interact with other students in class, students showed stronger learning gains. In addition to supporting the ICAP framework, this demonstrates that the type of questions posed to students can impact their level of learning. Another study designed instructional activities in a college physics course to reflect ICAP levels, such that lecture was the Passive condition, an individual writing activity was the Active condition, and peer instruction (Mazur, 1997) was the Interactive condition. Students in the Interactive condition showed higher learning gains than students who listened to lecture or engaged in the writing activity individually (Henderson, 2019).

Although several studies have demonstrated that instructional activities can be designed to reflect the ICAP hierarchy of learning levels, their limitation is the assumption that all students are cognitively engaged at the level required for the activity and are engaged throughout. By relying on student performance to measure learning, and without observing student behavior and listening to student talk, it is hard to determine students' cognitive engagement in the designed activities. Therefore, in addition to considering the overt behaviors associated with each level of the ICAP framework, it is necessary to record, listen, and analyze student thinking and talk to understand exactly how they are engaging with an activity.

To address concerns of the expected versus observed level of cognitive engagement for a designed activity, El-Mansy, Barbera, and Hartig (2021) recorded student group conversations as they completed worksheets in an undergraduate chemistry course. Both the worksheet questions and group conversational responses were coded using the ICAP framework to identify possible mismatches in the intended level of cognitive engagement for the activity and the students' actual engagement with each. They found that for all questions coded as Constructive or Interactive, group responses matched the intended cognitive level. However, for more than half of the questions coded as Active students responded at a higher engagement level than was intended, which was attributed to unclear expectations and unfamiliar vocabulary (El-Mansy, Barbera, & Hartig, 2021). The authors suggest that worksheet questions should be structured to scaffold student thinking in a way that mirrors the ICAP hierarchy by activating prior knowledge and then applying or synthesizing it to foster a deeper understanding.

Dialogue patterns between pairs of students have also been examined using the ICAP lens to determine if dialogue patterns are associated with the amount of learning. According to Chi and Menekse (2015), in student dyads where there is an unequal engagement in the activity, such as one student engaging constructively (speaking) and the other actively (listening), the constructively engaged student learns more. Moreover, the dialogue pattern of both students engaged constructively is the most supportive of learning, as students contribute to each other's ideas in a collaborative way (Chi & Menekse, 2015). This was evidenced by an experimental study in which engineering students were assigned to either a Constructive or Interactive learning activity to compare the learning gains associated with each condition. Students in the interactive condition participated in dyads and their conversations were recorded and analyzed for interactional quality and discourse moves (Chi & Menekse, 2019). Findings indicated that students in the Interactive condition performed significantly better than those in the Constructive condition. However, there was no significant difference in performance between dyads with low interaction quality scores and students who engaged in the Constructive (individual) condition. Discourse analysis revealed that the most common moves were “accept” and “elaborate,” which had opposite effects on student learning such that when dyads accepted each other’s ideas without adding anything they did not learn significantly, whereas dyads that elaborated or added new ideas learned significantly because they were both being constructive rather than active (Chi & Menekse, 2019).

The ICAP framework demonstrates that simply engaging with another student does not translate into higher performance. Learning is dependent on the nature and quality of the interaction, such that only when both students are engaged Constructively is the interaction truly considered Interactive and supportive of the highest level of learning (Hodges, 2018). Indeed, numerous studies have explored the benefits of interactive discourse in small group and peer-led learning. From their investigation into small group learning in math, Yackel, Cobb, and Wood (1991) share that a unique opportunity for learning arises when students engage in problem solving and sense making together. Explaining one’s ideas to a peer helps students clarify their understanding and without this dialogue, students may not become aware of errors in their own thinking. Moreover, listening to a peer’s explanation and having to reconceptualize one’s own thinking is beneficial as students work together to reach a consensus that makes sense (Yackel, Cobb, & Wood, 1991).

The discourse of small group learning led by a peer has also been investigated to understand how the nature of the interaction affected student learning (Sawyer et al., 2013). Using conversation analysis, two groups of chemistry students participating in peer-led team learning were compared. Students in the more collaborative group asked questions, shared instructions and equations, and provided conceptual explanations. Their discourse was aimed at increasing the collective knowledge of the group, such that they tried to understand the concepts associated with the equations they were using rather than simply applying them in a rote manner. Students in the less collaborative group worked independently, only asking task-oriented questions and sharing their answers without explaining the procedure or underlying concept. Conversation in this group was not focused on promoting group knowledge and the peer leader did not encourage in depth discussion (Sawyer et al., 2013). This shows that when student comments are made in coordination and build off one another, students collectively improve their ideas, leading to deeper understanding and knowledge building.

The nature of peer led group discourse when learning science content has also been characterized as either regulative or instructional. Regulative discourse works to establish certain behaviors among students to promote discussion, while instructional discourse describes the particular content being learned (Christie, 1995). While both were necessary to help students succeed in the learning task, certain instructional moves were more effective in promoting student learning. For example, when peer leaders asked more open-ended questions that elicited conceptual explanations, students were prompted to explain the concept in their own words which helped them monitor and assess their understanding (Repice et al., 2016). Similarly, Leupen et al. (2020) found that when prompted by higher level cognitive questions on a worksheet, biology students working in groups had more conceptual explanations, reevaluations and co-constructing of ideas in their conversations.

Kulatunga and Lewis (2013) explored peer leaders' verbal behaviors when working with small groups of chemistry students. Using discourse analysis to characterize their behaviors, they found that peer leader discourse is a collection of mediating moves such as probing and clarifying, offering suggestions, acknowledging, and confronting discrepancies paired with short questions to elicit expected responses. They suggest that when combining short questions with mediating behaviors, peer leaders are providing instructional scaffolding by creating a reciprocal discourse to help students focus on the learning task, ask questions, and produce explanations, all which promote learning (Kulatunga & Lewis, 2013). These findings are in contrast with those indicating that open ended, higher cognitive questions facilitate student learning more so than short, closed questions from peer leaders (e.g., Repice et al., 2016). While the learning context and use of peer leaders are different, this suggests that the collaborative discourse of peer-led small groups warrants further exploration to understand how the language of peer leaders supports student learning and fosters interaction. The following sections discuss the implementation and impact of peer learning assistants with respect to student learning.

2.4 Implementing Peer Learning Assistants

PLA pedagogical training

To achieve course transformations and promote active learning, many universities have implemented learning assistant programs. Many of these universities have adopted the Learning Assistance Model that was created by the University of Colorado Boulder and have become part of the "LA Alliance" (learningassistancealliance.org). However, other institutions of higher education have initiated their own PLA programs similar to that of UC Boulder but differ in their programmatic objectives. What is shared between all PLA programs are three central tenets: content, pedagogy and practice (Otero et al., 2006). PLAs meet weekly with the instructor they are assisting to review content matter, class activities, and student challenges (Figure 2.1). Additionally, (first semester) PLAs attend a weekly pedagogy seminar to discuss learning theories, instructional strategies, and educational research papers and share reflections on their teaching progress and goals. PLAs then put what they have learned from their content reviews and pedagogy training into practice in the classroom during their interactions with students (Otero et al., 2010).

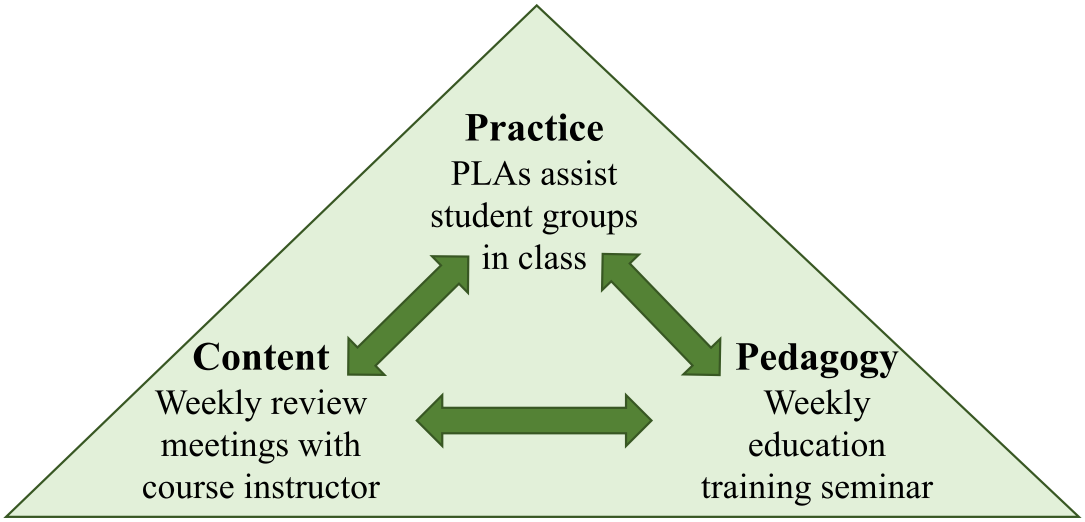


Figure 2.1: The PLA learning experience, including the three tenets of the PLA program, adapted from Gray and Otero, 2008.

While there are no uniform standards for PLA pedagogy training, a review of the literature from the original architects of the LA Alliance program revealed three overarching themes (Gray, 2013; Top et al., 2018). The first theme focuses on *what it means to learn something*, specifically how students make meaning of information, build their own understandings, and construct knowledge. By thinking about how students learn, PLAs recognize the importance of student ideas and the role those ideas play in generating knowledge.

This leads into the second theme of *student ideas*, in which PLAs are introduced to misconceptions, prior knowledge, and mental models and how these three ideas can be used to construct new knowledge. PLAs learn that students enter the classroom with varying levels and types of prior knowledge, and they must be able to adapt their teaching to be responsive to the needs of each student. PLAs can assess students' prior knowledge through questioning and then respond according to the students' individual needs. For example, they may continue with more guided questioning, provide an alternative explanation, or offer a real-life example to illustrate the concept (personal observation). From this, PLAs learn the value of student ideas, such that they serve as a starting point that can be used to bridge where students are cognitively to where they need to go.

The final theme is the purpose of *formative assessment and questioning* to elicit student ideas and identify gaps in knowledge and then to use that information to help students generate their own understanding of the content. Formative assessment is often presented as the bridge that PLAs use to identify gaps in student conceptions and develop a strategy to help build those conceptions into a complete and accurate framework for understanding. PLAs learn that students' ideas, even those that are inaccurate, are necessary because they are the foundation upon which students construct new knowledge. Students' prior knowledge often contains misconceptions or gaps, and PLAs can use guided questioning to spot them in their interactions with students and plan how to address them (Gray, 2013).

There is considerable overlap between these themes, but the overarching aim of PLA pedagogical training can be summarized as PLAs using questioning to elicit student ideas and then guide student explanations to build understanding. PLAs are trained to ask guiding questions rather than just provide answers, which encourages students to reflect on and explain their thinking (Otero et al., 2010). Through discussions with students, PLAs can diagnose misunderstandings from students' questions and responses. Through this iterative cycle of questioning and explaining, PLAs help students identify what they do not know or understand, an important aspect of metacognition.

Several studies have examined PLA's perspective of pedagogy training. For example, PLAs discussed their value of student thinking and ideas, describing them as "seeds of science." Identifying these "seeds" helped them understand students' line of thinking and create a path for sense-making. PLAs recognized that student ideas are productive, and they acted as co-learners with students to foster dialogue that would build on student thinking (Lovegren & Robertson, 2014; Robertson et al., 2014). Interviews with PLAs also revealed that they understand the significance of questioning to elicit student thinking and prioritized those exchanges over students getting to the right answer (Gray, 2013). Furthermore, PLAs discussed how they used formative assessment and students' prior knowledge to illuminate what students were thinking. Once the PLAs understood the students' conceptions, they would ask more questions that would encourage the students to reflect on and reason through their ideas. PLAs reported using these practices to support students' knowledge construction, enhance their conceptual understanding, and develop their metacognitive skills (Gray, 2013; Gray & Otero, 2008).

Other perspectives from PLAs regarding their experience as peer leaders reveal the experiential nature of their learning, such that PLAs developed their teaching by engaging in the STEM classroom as a student teacher, discussing student interactions with other PLAs, and learning new skills through pedagogical training. In particular, PLAs described the pedagogy training course as instrumental in their development as peer teachers, because they had to reflect on their experience as both a learner and a teacher to ultimately adapt their teaching skills and attitudes towards STEM classes (Gong et al., 2022). In addition to pedagogical training, another study found that PLAs' experiences as students were also instrumental in the way they approached peer-teaching. PLAs described using both cognitive and relational strategies to support student learning. Cognitive strategies were reflective of topics discussed in PLA pedagogy training and included asking guiding questions, eliciting student thinking, and providing alternative explanations. However, PLAs discussed using relational strategies including making students comfortable and attending to student differences and shared that these actions were a result of their prior experiences as learners (Ferrari et al., accepted).

These studies demonstrate that pedagogical training is important for PLAs to not only develop their peer teaching skills, but also to reflect on their experiences and grow as peer-learners and teachers. Moreover, PLA perspectives about their pedagogical training have been used to improve these training courses. For example, PLA and course instructors were surveyed to understand how they perceived the use of PLAs, the integration of PLAs with the curriculum, PLA training and development, and instructor support of PLAs. While PLAs and instructors shared similar perceptions about PLA use and efficacy, responses indicated that PLAs could be better integrated into the curriculum and professional development should be a more explicit component of their training (Campbell et al., 2019). Improvements to other PLA pedagogy training have been made in response to “challenging interactions” PLAs experienced with students. These “challenging interactions” were then incorporated into pedagogy training by reenacting the scenarios and reflecting on how to properly navigate them to better facilitate students’ deep learning (Purtell et al., 2020).

2.5 Impact of Peer Learning Assistants

Impact on Student Outcomes

Much of the literature regarding PLAs’ impact on student learning is centered around achievement, typically measured by comparing exam scores, course grades and concept inventory performance between students in PLA and non-PLA supported courses (Otero et al., 2010; Talbot et al., 2015b; Van Dusen et al., 2015; White et al., 2016). For example, Herrera et al. (2018) found that including PLAs in a collaborative learning environment was correlated with higher learning gains than the collaborative learning environment alone. Similarly, another study sought to isolate the effect of PLAs on student performance from a highly structured, flipped classroom and found that PLAs were not associated with learning gains on concept inventories but were positively correlated to increased performance on exam questions requiring higher order cognitive skills (Sellami et al., 2017). This is consistent with another study that compared student performance between two college biology courses. One completed in-class active learning exercises in collaborative groups while the other completed the same exercises independently. Results showed that there was no difference in low cognitive level performance but students that learned collaboratively performed significantly better on high cognitive level questions on the exercises (Linton et al., 2014). These studies suggest that peer interaction supports active learning, but perhaps only for higher order cognitive processing on activities and exam questions.

To further explore the types of learning activities in which PLAs can be used to best support student learning, Ferrari et al. (2023) compared student performance on unit exam questions that aligned with clicker questions (short, multiple-choice questions posed to the class using electronic polling software) and open-ended worksheet questions when PLAs were present versus absent in a college biology class. Findings revealed that when PLAs were present, students performed better on unit exam questions that aligned with open ended worksheet questions but there was no significant difference in performance for unit exam questions that aligned with clicker questions when PLAs were present. The authors suggest that this was due to the nature of the assignment, such that while completing open-ended worksheets students have more time and opportunity to engage with PLAs. Specifically, PLAs and students can have more substantive discussions that include unique feedback responsive to the student's questions, rather than receiving the same mass feedback after a few minutes of considering a clicker question (Ferrari et al., 2023).

Several studies have explored the impact of PLAs on student retention, satisfaction, and persistence in college science courses. One study found that student exposure to PLAs in any introductory STEM course was associated with a 63% or 55% reduction in odds of failure for males and females, respectively (Alzen et al., 2018). Another study assessed how PLAs contributed to student learning, overall instruction, and general satisfaction in five PLA-supported science courses. Survey analysis indicated increased student satisfaction and self-reported learning in the course due to interactions with PLAs in the classroom, rather than as a resource outside of class (Talbot et al., 2015a). PLAs have also enhanced students' sense of belonging in STEM by lessening feelings of isolation, being role models, providing mentorship about the STEM pipeline, and supporting student engagement and confidence in STEM-related skills (Clements et al., 2022). Finally, STEM students who participated in social learning experiences with a PLA were more likely to develop their metacognitive awareness and have a positive disciplinary identity than when participating in individual learning experiences (Kornreich-Leshem et al., 2022).

The efficacy of PLAs versus Graduate Teaching Assistants (GTAs) has also been evaluated by asking students to compare the PLA and GTA's demeanor, effectiveness, attitude, and content knowledge in addition to students' attitude towards science. Survey analysis indicated that PLAs were more successful at encouraging students to ask questions and making them feel respected than GTAs. Additionally, students taught by PLAs were as likely as those taught by GTAs to have positive attitudes towards science (Chapín et al., 2014). Finally, the effect of PLAs and GTAs on student persistence in college chemistry courses has also been compared. Enrollment records indicated that students in PLA-supported chemistry courses more strongly identified as a "science person" and were more likely to enroll in the next chemistry class in the sequence the following semester compared to students supported by GTAs (Philipp et al., 2016b).

None of the research discussed so far has directly examined the impact of PLA training on student learning. It could also be argued that none of the studies discussed actually investigated student learning, since achievement was used as a proxy for learning. While performance is a useful way to evaluate the impact of PLA support, it does not provide clarity on how PLA facilitate student learning. Therefore, despite numerous studies documenting the impact of PLAs on student achievement and satisfaction, we still do not know much about the ways in which PLAs help students learn. However, some work has been done to address this need and frameworks have been presented that may be useful for characterizing PLAs' instructional practices.

A few studies have examined the specific actions of PLAs and the effect they have on facilitating student learning. Talbot et al. (2015a) used social network analysis to understand how PLAs can facilitate student interactions in the classroom. They argued that more interactions would lead to more engaged students, thus creating an active learning environment resulting in greater learning gains for students. Results of the analysis revealed that PLAs were the central figures in the classroom network and that connectedness among students increased over the course of the semester. This suggests that PLAs foster interactions between students and even though the number of overall interactions did not increase over the semester, the nature of their communications may have been of more importance because students were consistently interacting with the same people. Given how some PLA-supported classrooms are arranged, such that students are assigned to groups that they collaborate with throughout the semester, these results are encouraging. This is consistent with aspects of PLA pedagogy training, namely facilitating discussions and collaborative learning, and suggests that PLAs are able to enact that training to foster student interactions.

The role of PLAs facilitating student interactions was also investigated in the context of argumentation and student discourse during clicker questions. Argumentation is an important skill for science students to learn but this active learning strategy is difficult to implement in large classes (Knight et al., 2015). It was hypothesized that PLAs may be effective at encouraging, modeling, and supporting students' argumentation during clicker questions. To investigate, audio recordings of student group discussions were used to examine how the presence of PLAs impacts student discourse during clicker questions. Analysis revealed that different questioning prompts by the PLAs influenced the quality and quantity of students' discussions. When asked for reasoning, students were more likely to expand on their argumentation discourse, but when the PLA provided reasoning, students were more likely to end the discussion (Knight et al., 2015). This indicates that students respond differently depending on the PLAs' cues, suggesting that PLAs can influence student discourse during classroom interactions. This also connects to aspects of PLA training, such as the questioning techniques and approaches for facilitating discussion, suggesting that PLAs may implement practices they learned in pedagogy training during their interactions with students.

Recently, Thompson et al. (2020) developed the Action Taxonomy for Learning Assistants (ATLAs) tool, which outlines actions that PLAs do in the classroom. These actions include PLA-Directed Facilitation, PLA-Guided Facilitation, Feedback, Advice, Course-Related Talk, and Non-Course-Related Talk. The Directed Facilitation action refers to PLAs providing information and explaining, while the Guided Facilitation action refers to PLAs creating opportunities for students to share their ideas. Feedback refers to the PLA evaluating student responses and affirming or correcting, and Advice relates to PLAs providing students helpful information to be successful in the course. Course-Related Talk and Non-Course Related Talk describe PLAs talking to students about things related to the course, but not the current activity and things not related to the course, respectively. While the ATLAs tool has not yet been applied, the authors claim that it is useful for exploring PLA-student interactions from a pedagogical standpoint in addition to characterizing how PLAs support student learning and engagement (Thompson et al., 2020).

Student perceptions of PLAs have been explored with respect to their role in supporting student learning. Survey analysis from 19 Likert-style questions revealed that students largely agreed that PLAs used a variety of practices that were beneficial for learning, most frequently helping to clarify ideas and explaining concepts. They also reported having considerable trust in and strongly valuing the PLAs (Ferrari et al., 2023). Another study developed an instrument to measure the students' perceptions of the social supports for active learning in the classroom. Students perceived that LAs provided appraisal, emotional, and informational support and all three forms of support significantly predicted deep engagement in active learning (Hernandez et al., 2021). These studies demonstrate that students find value in the support provided by PLAs in the classroom, and perceive that support as beneficial for their learning as it enables them to more meaningfully engage in learning activities.

Impact on PLAs

The nature of pedagogical training for Learning Assistants is characterized as helping students learn (and learning how to learn) rather than learning how to teach (Gray et al., 2016). From this viewpoint, PLAs themselves must learn how to learn in order to help others do so. This is not to say that learning to teach is not a worthwhile endeavor. However, a Reformed Teaching Observation Protocol (RTOP) comparison between first-year science teachers that were previously PLAs and those that only completed traditional teacher certification showed that teachers who were PLAs outperformed their counterparts on most RTOP factors and used more reformed practices overall (Gray et al., 2010). As both groups completed teacher certification training, the difference was attributed to the PLAs' pedagogical training and the opportunity they had to "try out" their ideas about teaching and learning while getting immediate feedback from students regarding PLA support. In addition to professional benefits, there is also evidence of numerous cognitive gains for students that serve as PLAs stemming both from their pedagogical training and enactment of that training into classroom practices.

Research documenting outcomes for PLAs indicates that they experience numerous cognitive benefits such as deeper conceptual understanding of the content they are teaching, familiarity with teaching strategies, and development of their metacognitive awareness (Atieh & York, 2022; Close et al., 2016; Ford et al., 2018; Jardine & Friedman, 2017). Interviews with PLAs have revealed more about their personal reflections on the development of their metacognitive skills. For example, PLAs recognized that they were starting to think metacognitively when they were struggling with concepts in their own courses and directly related that skill to their experience as a PLA (Conn et al., 2015). Another PLA reported improved metacognitive skills, stating that thinking about thinking was something they hadn't practiced before being a PLA and it helped them relate to how their students learned (Philipp et al., 2016a). Other PLAs described how reflecting on the pedagogy course and classroom interactions enabled them to better manage their understanding and consider alternate approaches to problem-solving (Close et al., 2016). Finally, evidence suggests that the longer a PLA participates in the program, the more their metacognitive awareness and intrinsic motivation increases (Breland et al., 2023).

2.6 A Framework: Peer-led Interactive Discourse

The echoing calls to transform undergraduate science classrooms into student-centered learning spaces are almost deafening, yet they frequently fall on deaf ears. Efforts to advance active learning are numerous, but are not ubiquitously taken up, leaving some students to passively listen to lectures while others actively engage with their peers to learn course content. At its core, learning is meant for students. Putting student thinking, rather than instructor lecturing, at the forefront of our courses is meant to benefit the learners. How is it that we instructors are supposed to know if students are learning anything we teach them if we do not know what they are thinking? How can students monitor their understanding without having a moment to stop and ask themselves, "does this make sense to me?" Trying to gauge student learning from assessments alone, while a common and expeditious practice, cannot tell us what they truly understand of the content we teach.

If we aspire for students to practice scientific thinking, i.e., incorporating new knowledge into their pre-existing knowledge, they should be presented with opportunities to think through that process. This requires students to articulate their thinking, engage in formative assessment, and receive frequent feedback. Yes, this instructional approach may be challenging to implement in large-enrollment courses, which many college science courses typically are. However, students can learn a lot from interacting with their peers, especially those who have taken the course previously and are trained to elicit student thinking. Learning is inherently social, as students' cognitive activity is stimulated by and developed through their interactions with others (Cobb, 1994). Therefore, the sociocultural perspective of learning is essential for understanding the efficacy of peer-assisted learning.

In peer-assisted learning, the PLA represents a *more knowledgeable other,* providing instructional scaffolding to help students examine their thinking to make meaning of information and build understanding (Vygotsky, 1978). PLAs engage in discourse with students to probe them about their thinking, thereby helping students activate prior knowledge and identify what they do not know. Through these interactions, PLAs use formative assessment and provide frequent feedback to students as they make sense of new information. This demonstrates to students the ways in which scientists reflect on their understanding in light of new information in order to generate knowledge. In this way, PLAs enculturate students into the scientific community by illustrating scientific thinking and ways of knowing. Learning, and ultimately knowledge construction, is a result of both the scientific thinking practices and social interactions students experience in the science classroom community (Lave & Wenger, 1991).

The interactive discourse between students and PLAs is integral to support learning, as it is through participating in these interactions that students clarify their thinking and work to build understanding. As student groups interact with a PLA, they engage in problem solving, consensus seeking, and make genuine attempts to communicate their ideas. This discourse provides an opportunity for students to reconceptualize their own thinking as they try to make sense of their peers' explanations (Yackel et al., 1991). When engaging interactively, student ideas build off one another as they seek to collectively make sense of new information (Chi & Wylie, 2014). Without this interactive discourse, students may not become aware of their misconceptions because they are not able to share their thinking out loud. PLAs serve as mediators, using a variety of instructional moves to guide students' thinking towards a higher level of understanding. Moreover, PLA interactions with student groups shape their discourse, such that students are enculturated into the scientific community by engaging in practices that promote productive collaboration and knowledge sharing.

My analysis of peer-assisted learning is informed by Cobb and Yackel's (1996) emergent perspective because I contend that student participation in interactive discourse is necessary for learning. According to Cobb and Yackel (1996), "learning is a constructive process that occurs while participating in and contributing to the practices of the local community (p. 185)." In my study, the local community is the science classroom, and interactive discourse is the practice through which communal learning occurs. Only by actively participating in this discourse, can students explain their thinking and build understanding with peers. This perspective is unique in that it focuses on the communal activity of learning, rather than students' individual actions, as the explicit objective of the analysis. In this view, learning is the result of the interaction, and therefore the unit of analysis (Cobb & Yackel, 1996).

Peer-assisted learning is a participatory and interactive process that creates a community of learners through discourse. The framework that I will use to guide my study is *peer-led interactive discourse* (Figure 2.2). The peer-led component of this framework is informed by the extensive evidence illustrating that students benefit from learning from near-peers. The interactive piece represents the *Interactive* mode of cognitive engagement, which posits that by building ideas off each other to co-construct knowledge, students can attain the highest level of learning (Chi & Wylie, 2014). Finally, discourse is the avenue through which these peer-led interactions occur. Taken together, peer-led interactive discourse is that which students and PLAs participate in to collectively build understanding. This framework will allow me to examine what PLAs and students are doing when they communicate in their interactions, and whether their communication is supportive of student learning. Figure 2.2 illustrates my conception of the *peer-led interactive discourse* framework.

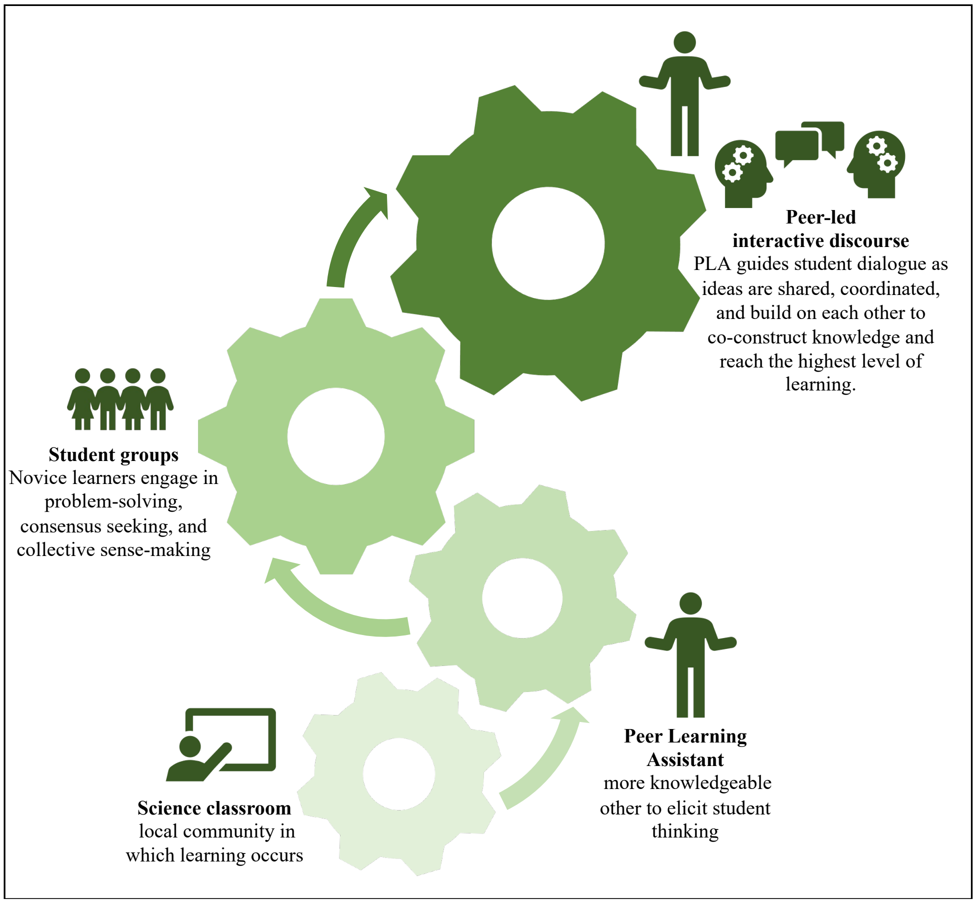


Figure 2.2: The peer-led interactive discourse framework. The individual pieces of this framework, including the science classroom, all work together in order for students to achieve deep learning through peer-led interactive discourse.

CHAPTER 3

METHODS

3.1 Overview of Research Design

Guiding Theoretical Frameworks for Methodology

Traditionally, the term “paradigm” has been used to describe different worldviews, or epistemologies, about the nature of knowledge (Morgan, 2007). One paradigm with roots in the sciences is positivism, which reflects an objective worldview that assumes an absolute, observable, and measurable reality. This epistemological lens focuses on determining cause and effect relationships using logical, deductive reasoning (Okasha, 2016). Post-positivism also asserts that there is an objective reality but recognizes that human interactions with that reality cannot be ignored (Creswell & Creswell, 2018). The constructivist (or interpretivist) worldview assumes that all meaning and knowledge is socially constructed by humans as they actively participate in the world. Humans’ interpretations of their prior experiences, social and cultural interactions, and natural phenomena are the basis of meaning making and knowledge construction (Crotty, 2003).

The paradigms described thus far are rigid in their opposing definitions of reality, objective truth, and what is knowable. Morgan (2007) argues that conceptualizing paradigms as epistemological worldviews that are incommensurable with one another is problematic for social science research and instead offers a pragmatic approach. Pragmatism accepts that the world is objectively knowable and acknowledges that humans interpret the world through their unique interactions with it (Morgan, 2007). The way that humans construct meaning is based on their social and cultural experiences, and therefore that meaning can take on different forms for different people. However, there is still an observable world that exists outside of human interpretation. This approach resolves the stark differences between positivism and constructivism (Creswell & Creswell, 2018), thus creating a new space for researchers to think about the nature of knowledge. Pragmatic research is guided by attaining desired, practical, knowable outcomes, rather than the abstract pursuit of knowledge (Cherryholmes, 1992; Morgan, 2007).

I used the pragmatic approach as the guiding theoretical lens in this study as it aligns with my personal worldview, which assumes that there is an objective world, such that knowledge exists outside of our understanding of it. However, I accept that individuals come to understand that knowledge in different ways based on their interaction with the world. Knowledge construction is mediated through interactions with peers, culture, and society. The meaning of this knowledge varies among individuals and changes over time as more knowledge is accumulated through our experiences and interactions (Dewey, 1938).

Symbolic interactionism (SI) is an interpretative research tradition that involves studying individuals, how they interact with one another, and how their interactions form a shared society. SI emphasizes individual sense making and the role of self in construction of reality, while asserting that a person's sense of self stems from their interactions with others (Prasad, 2015). SI assumes that individuals act towards objects based on the meaning the objects hold for them. The meanings of such objects are constructed by humans' social interactions within a larger society. Object meanings are not concrete, but constantly modified through a series of interpretations and social negotiations, and thus change over time (Prasad, 2015). In this way, knowledge is comprised of socially constructed meanings humans have given to objects. SI that is informed by pragmatism recognizes that these objects are real and objective, but our understanding of them is based on our subjective interpretations and social negotiations.

SI seeks to understand the role of language, communication, interrelationships, and community in social interactions (Crotty, 2003). This is in keeping with a pragmatic approach, as it also emphasizes communication. Specifically, understanding how language and meaning are used in human interactions is essential to pragmatism (Morgan, 2007). Meaning is given to one's own knowledge, so how individuals think about and define knowledge matters. Additionally, the meaning that individuals ascribe to knowledge is negotiated in the community in which they are participating. For example, knowledge is intertwined with culture and the way that the scientific community understands knowledge and how it is produced is unique to those within this community. Therefore, the scientific community has a shared understanding of what it means to know something. Interactive discourse plays an integral role in the construction of knowledge because it requires that we reflect on what we actually understand in order to communicate. Therefore, understanding what it means to know something is critical and symbolic interactionism is an appropriate research theory to illuminate that meaning.

This study utilized qualitative inquiry through analysis of audio recordings of student interactions with PLAs as they worked collaboratively in groups. Specifically, I used discourse analysis to examine student engagement in PLA interactions and the nature of student contributions to their group's discussion. By considering the language that students and PLAs used and the way they used language in their interactions, I analyzed the ways in which students engaged in knowledge building discourse and how PLAs supported that discourse. Moreover, I explored patterns between student engagement and group dynamics during PLA interactions during and considered how these factors might mediate student performance. Although student performance is not necessarily indicative of student learning, I chose to include it in this study to complement the findings from my discourse analysis. I believe that by doing so, I gathered a more nuanced understanding of the phenomenon as these data were integrated to inform a robust interpretation to address the following research questions:

RQ1. In what ways do PLA practices facilitate student knowledge construction while students work collaboratively in groups?

RQ2. How do student engagement and group dynamics during PLA interactions mediate performance?

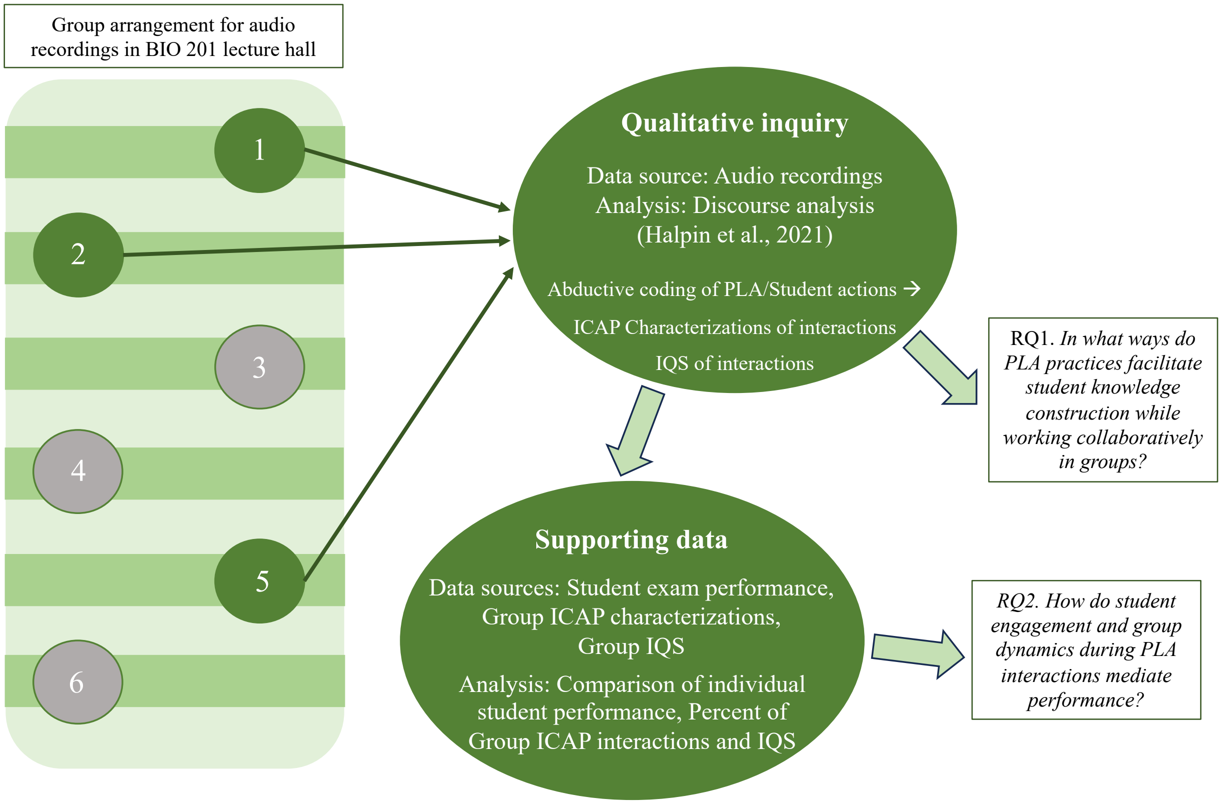


Figure 3.1: Overview of research design.

3.3 Study Design

Research Context

This study was conducted in an introductory biology course (BIO 201) at a large, research-intensive university in the southeastern United States during the spring 2022 semester. The BIO 201 course focuses on information flow and evolution and is divided into five units (Table 3.1). It is the first course in a two-part introductory biology course sequence (Principles of Biology) that is required for all science majors at this university. These courses were reorganized during the summer of 2020 to better align with the learning outcomes outlined in *Vision and Change* (AAAS, 2009) for undergraduate biology education. I collected data in one afternoon section of BIO 201 taught by Dr. Daniel James. The approximate class size for each section of BIO 201 was 155 students. Peer Learning Assistants were used in this section to help facilitate active learning. The syllabus for BIO 201 can be found in Appendix A.

Table 3.1

BIO 201 Content Units

Unit	**Content**
1	Gene Expression
2	Cell Division
3	Reproduction
4	Trait Inheritance
5	Evolution

PLAs have been incorporated in introductory biology courses at this institution for several years and fulfill similar roles across courses and instructors. The three tenets of the PLA program at this university are pedagogy, content, and practice. All first-semester PLAs must complete a pedagogy training seminar course (UNI 204) that is offered by the Division of Academic Enhancement (DAE) at the university. The syllabus for UNI 204 centers around activating and organizing knowledge, diversity, learning strategies, active listening and providing feedback, and self-regulated learning (Appendix B). PLAs also receive content training through weekly meetings with their assigned instructor to review upcoming content, group activities, and student challenges that may be encountered in the upcoming classes. Lastly, PLAs put into practice what they have learned from their pedagogy training and content review meetings in the classroom to guide their interactions with students.

To become a PLA at this university, PLAs are selected through a competitive application process, faculty references, and interviews. According to DAE, the organization responsible for hiring and placing PLAs at this university, students applying to be a PLA must have completed at least one semester of classes, have a minimum 3.25 overall GPA, and have earned a B or higher in the course for which they are applying. Additionally, they must be able to work collaboratively, possess leadership and problem-solving skills, have a desire to assist in their peers' learning, and demonstrate excellent communication skills and a patient approach to explaining concepts.

Course Format

BIO 201 is a traditional lecture course, but it includes frequent opportunities for active learning as students work collaboratively in groups on clicker questions and worksheet assignments. Students self-select into groups of three at the start of the semester. Clicker questions are used frequently throughout the class as formative assessment (about five questions per class period). These are multiple choice questions posed to students throughout lecture that can be answered using a mobile phone, which allows the instructor to collect and display student responses. In BIO 201, students have approximately three to five minutes to deliberate with peers in their group and respond to the clicker question. During this time, PLAs circulate throughout the room to address student questions and provide feedback to students. Worksheet assignments include 10-12 open-ended response questions and are used in this course at the end of each unit as a practice exam activity for the unit exam (Table 3.2). A majority of the questions on each practice activity worksheet were written to align with an exam question from the corresponding unit. An entire class period (75 minutes) is allotted for the worksheet assignment, as students collaborate with peers in their group. PLAs visit student groups and engage in interactive discussions that provide scaffolding to guide student thinking by asking questions and offering feedback, rather than providing direct answers. The practices that PLAs use to elicit and guide student thinking are generally consistent with their pedagogical training (personal observation).

Table 3.2

Topics covered in the practice activity worksheets and corresponding unit exam questions

Practice Activity Worksheet	Number of Questions	Number of Questions Aligned with Unit Exam	Topics Covered on Worksheet
1	10	10	DNA/RNA Structure Protein Structure and Synthesis Transcription and Translation
2	12	9	Gene Regulation Genetic Mutations DNA Replication
3	12	10	Mitosis and Meiosis Genetic Variation Life Cycles
4	9	11	Mendellian Inheritance Sex-linked Inheritance Genetics and Probability
5	8	7	Hardy-Weinburg Equilibrium Methods of Speciation Phylogenetics

PLA Selection

Prior to the start of the study, 10 PLAs were assigned to the section of BIO 201 in which data collection occurred. All PLAs were given a consent form and asked to complete an eligibility survey (Appendix C). Nine PLAs consented to participate in the study, and of those, four had previously served as PLAs for BIO 201 before. Utilizing experienced PLAs was essential for this study, as it was predicted that they would be more familiar with the course content, comfortable interacting with students, and confident engaging in pedagogical approaches consistent with their training. Therefore, the four consenting PLAs that had prior experience as a PLA in BIO 201 were selected for this study.

As part of their PLA responsibilities, all 10 PLAs attended every class session of the section of BIO 201 they were assigned to during the spring 2022 semester. During class, they sat in the back of the lecture hall while Dr. James lectured. When Dr. James posed clicker questions to the class, PLAs assisted students as they deliberated and responded to the clicker questions. On unit exam review days, PLAs circulated around the room to interact with groups as they completed practice activity worksheets. In addition, Dr. James and I met with the PLAs outside of class each week to review the upcoming lecture content, clicker questions, and common student questions. These review meetings were especially important before the unit exam review days, as Dr. James went through the practice activity worksheets by explaining each question, answer, and anticipated student misconceptions. These meetings also offered PLAs an opportunity to ask questions about the content, describe their interactions with students, and reflect on different approaches to support student learning. For example, PLAs shared that students were frequently asking PLAs to confirm they reached the correct answer, so as a group we discussed ways to prompt students to explain their thought process and probe for reasoning, rather than just confirming or providing answers.

Participant Criteria

Most students enrolled in BIO 201 are freshman and sophomores, although a small percentage are upperclassmen. To select students that would participate in this study, I identified several inclusion and exclusion criteria. Only students that consented to participate in the study and that met the following criteria were eligible to participate:

- Freshman students.
- Students taking BIO 201 (or equivalent) for the first time.
- Students that have natural science declared majors (no social science majors).

In addition to these criteria, I collected other demographic information from students during the consent process including their identified gender, race and ethnicity, as well as the highest biology course they had completed prior to BIO 201 (Table 3.3). Student high school course grades, SAT scores, and GPAs were not collected because it was assumed there would not be considerable difference in these values among students. The GPA of a freshman student admitted to this university in the fall 2021 semester ranged from 4.00 to 4.27 with an average of 4.12 and SAT scores ranged from 1350 to 1480. These statistics suggest that students admitted to this university are high performing students. Because I was more interested in their conceptual understanding and collaborative discourse, rather than academic performance, I did not find these metrics necessary to include as inclusion criteria.

Table 3.3

Student Demographics in BIO 201 (N=148)

		n	**%**
Identified gender	Female	103	69.59
	Male	44	29.73
	Prefer to self-describe as [Non-binary]	1	0.68
Race and ethnicity/ies (select all that apply)	African American	10	5.75
	American Indian or Alaskan Native	3	1.72
	Asian American	24	13.79
	Asian Indian	16	9.20
	Chinese	5	2.87
	Korean	4	2.30
	Latina/Latino or Hispanic	6	3.45
	Middle Eastern	1	0.57
	Native American or Other Pacific Islander	1	0.57
	Vietnamese	6	3.30
	White	98	56.32
Year of study	First year	115	77.70
	Second year	28	18.92
	Third Year	4	2.70
	Fourth Year	1	0.68
First time taking BIO 201	Yes	138	93.24
	No	10	6.76
Taken course with PLAs at this university before	Yes	67	45.27
	No	77	52.03
	Currently taking another course with PLAs	4	2.70
Highest biology course completed with a passing grade	College biology for science majors	7	4.73
	College biology for non-science majors	10	6.76
	Advanced placement biology	65	43.92
	High school biology	66	44.59

Participant Recruitment

After the drop/add period closed, students in the section of BIO 201 taught by Dr. James that was supported by PLAs were given access to a Qualtrics survey link through their course management site (eLC) during a class session. The Qualtrics survey began with a consent form

(Appendix D) describing the purpose of the study and asking students if they agreed to participate in the study. Students were asked if they agreed to:

- Complete all classwork normally associated with this course. This will include exams and worksheet assignments.
- Share results of their unit and final exams with the researchers of the study. If you agree, this will be handled automatically and no action is required on your part.

Students who agreed to participate in the study were guided to a second consent form, asking if they agreed to participate in audio recordings of their interactions with PLAs and other students while they completed group worksheet assignments in class. Following the informed consent, regardless of whether they agreed to participate in either component of the study, students were prompted to answer survey questions to determine their eligibility for participating in the study.

3.4 Data Collection

The central component of the qualitative inquiry was audio recordings of PLA-student group interactions in BIO 201. Student groups were recorded while they completed worksheet assignments that functioned as practice exams for upcoming unit exams. Students were given the entire class period prior to the unit exam to complete the worksheet with their group. This offered students ample opportunities to ask PLAs questions and for the PLAs to prompt and guide student thinking. Because these worksheets were presented as practice exams, students took them seriously and put considerable effort into working through the problems. The worksheet assignments were graded for completion, rather than accuracy. Previous research indicated that students perform significantly better on unit exam questions that correspond with worksheet activity questions when PLAs were present. There was no difference in student performance on exam questions that corresponded with clicker questions when PLAs were present versus absent (Ferrari et al., 2023). For these reasons, I chose to only audio record PLA-student interactions during group worksheet assignments rather than clicker questions.

Eighteen students were selected from the list of students who consented to participate in the audio recording component of the study. I used their survey responses to the demographic questions to select a sample of students that represented the demographics of the whole class (Table 3.4). After identifying the students who would participate in the audio recordings, I sent them an email asking to meet me at the start of the class prior to the first recording session. I instructed the participants that the right side of the lecture hall would be reserved for the recording groups for each recording session of the semester. I asked students self-select into six groups of three because I wanted them to be able to choose who they worked with for the semester. I informed students they needed to work with the same group members for the entire semester, but only for the audio recordings, and they were free to sit wherever and work with whomever on non-recording class periods. Students were also made aware that they would be compensated with an Amazon gift card for their participation in the audio recordings, contingent on their attendance of the recording sessions.

Table 3.4

Students selected to participate in audio recordings (N=18)

		n	**%**
Identified gender	Female	13	72.22
	Male	3	27.78
Race and ethnicity/ies (select all that apply)	African American	2	11.11
	Asian American	4	22.22
	Asian Indian	2	11.11
	White	10	55.56
Year of study	First year	18	100.00
First time taking BIO 201	Yes	18	100.00
Taken course with PLAs before	Yes	18	100.00
Highest biology course completed with a passing grade	College biology for non-science majors	1	5.56
	Advanced placement biology	9	50.00
	High school biology	8	44.44

The six groups of student participants were isolated to the right side of the lecture hall and were staggered in the rows of desks to improve audio quality and clarity of the recordings. The four PLAs that were selected to participate in the study were instructed to focus on assisting these groups of students who were being recorded but were permitted to help non-participant groups in the near vicinity. The six PLAs who were not part of the study assisted all other students in the class who were not involved in the audio recordings. At the start of each recording session, I placed one SONY digital voice recorder on the desk in the middle of each group to record their discussion and interactions with the PLAs. Students were asked to start the recorder when they started working on the worksheet and stop recording when they finished.

I attended all class sessions for this section of BIO 201 during the spring 2022 semester. During the sessions in which student groups were recorded, I made field notes to document my observations of their group dynamics and interactions with PLAs. In addition, Dr. James and I met with the 10 PLAs assigned to this section of BIO 201 for one hour each week to review upcoming content and discuss group activities. After Dr. James described the upcoming lecture slides and class activities, I invited PLAs to share their observations of what concepts or activity questions students were struggling with. I also asked PLAs to explain how they assisted students and responded to their questions. Based on the PLAs' comments, I offered suggestions on how to prompt students to articulate their thinking and ensure that students understood why an answer to an activity question was correct. During each meeting, I made notes of the PLAs' statements and questions, in addition to my recommendations and the information provided by Dr. James.

In total, 30 audio recordings were collected from the six groups across five recording sessions. Of the six groups, I selected three to transcribe and analyze (Table 3.5). These groups were selected based on my observations of their ability to collaborate as a group and the frequency and length of their interactions with PLAs. Groups that had minimal discussions were not selected, as student engagement in collaborative discourse was central to the study. Moreover, groups that I observed having shorter interactions with PLAs were not selected, as I hypothesized that longer interactions with PLAs would yield more productive discourse and sense-making. After completing my analysis of these three groups, I felt that saturation had been reached, meaning that I found consistent, recurring patterns in their interactions and did not believe that anything new would be learned from transcribing and analyzing additional groups.

Table 3.5

Student groups included in discourse analysis (N=3)

Group	**Student pseudonym**	**Gender**	**Race / Ethnicity**	**Highest biology course completed**	**Major**
1	Laura	Female	White	Advanced placement biology	Biochemistry and French
	Kayla	Female	White	High school biology	Biology
	Tori	Female	African American or Black	College biology for non-science majors	Pharmaceutical Sciences
2	Sean	Male	Asian Indian	Advanced placement biology	Exercise and sports science
	Gina	Female	African American or Black	Advanced placement biology	Biological engineering
	Nick	Male	Asian American	High school biology	Biology
5	Farrah	Female	White	High school biology	Biology
	Peyton	Male	White	Advanced placement biology	Genetics
	Jamie	Female	White	High school biology	Psychology and Biology

3.5 Data Analysis

Audio recordings were initially transcribed using either Otter.ai or Rev.com transcription services. All transcriptions were then checked for accuracy and completeness. Overall, 15 audio recordings were transcribed (five from each group), totaling 901 minutes and 32 seconds and on average each recording was 60 minutes and six seconds long. Although I transcribed recordings in their entirety, only interactions between students and PLAs were analyzed. An interaction was considered to have started once a PLA entered the group's conversation or more commonly, when a student addressed a question to a PLA. Interactions concluded when a student thanked a PLA for their help and the PLA responded or, less frequently, when a PLA was no longer making audible contributions to the interaction.

Interactions were also bound by the worksheet question that was being discussed, such that if students started an interaction with a PLA by asking about one question and then moved on to a different question, each question was considered a separate interaction. I chose to make this distinction because I assessed student performance on individual exam questions that aligned with worksheet questions and I wanted to be able to consider the nature of PLA-student interactions for each question. In sum, there were 114 interactions across the three groups, totaling 336 minutes and 10 seconds, with an average of two minutes and 56 seconds per interaction. The shortest interaction lasted one second, in which a student asked a PLA to confirm their answer to a question and the PLA quickly confirmed it. The longest interaction was 12 minutes and 22 seconds.

RQ1. In what ways do PLA practices facilitate student knowledge construction while students work collaboratively in groups?

Student learning is a collaborative and interactional process that creates a community of learners through discourse. Therefore, to examine PLA-student interactions I used discourse analysis, specifically applying a turn-by-turn conversation analysis approach (Halpin et al., 2021). Conversation analysis has been used to examine how classroom interactions are conducted, and more recently it has been used as one approach to student learning as a social and interactional phenomenon (Gardner, 2019). Conversation analysis allows researchers to look for evidence of learning by focusing on an in-the-moment examination of the words and actions of the learner within the actual site that learning occurs (Hepburn & Potter, 2021; Walsh, 2011). I analyzed students' actions as they participated in interactions, which varied based on group dynamics and the nature of the learning task (Cobb & Yackel, 1996; Repice et al., 2016).

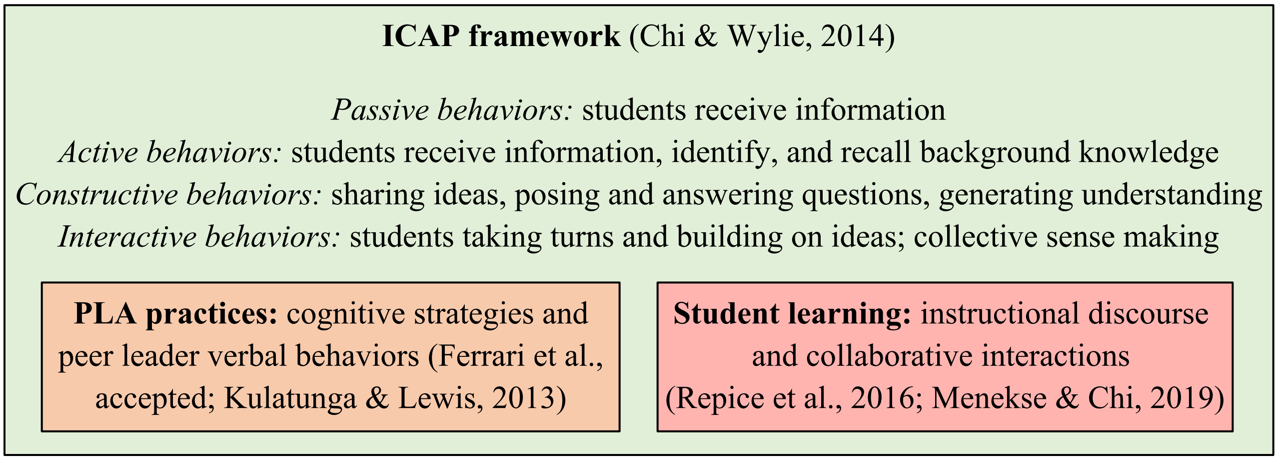
The unit of analysis was a turn, which was defined as a continuous segment of talk by the same speaker. As overlapping talk is common in multi-party interactions, I separated overlapping turns to capture the dynamic nature of student discourse. A single turn could consist of multiple utterances, and each was given an action code. Utterances were analyzed with process coding, which uses gerunds to describe actions (Saldana, 2015). I considered an action to be a discursive move taken by a student or PLA during their interaction that was directly related to the student accomplishing the learning task (Table 3.6). I used separate codebooks for students and PLAs to characterize the action each was trying to accomplish in their turn. Codebooks were developed separately and evolved as analysis progressed. Figure 3.2 illustrates the conceptual framework that guided my analysis of PLA-student interactions. Specifically, I used "PLA practices" to inform the codebook for PLA actions and "Student learning" for the codebook of student actions.

Table 3.6

Example of discursive moves identified as student and PLA action codes

Transcribed talk	Discursive move (initial open process code)	Action code
Sean: I'm thinking it would be single finned fish. I don't know if it could be both. I haven't checked that out yet. But so far, I've been thinking single finned goldfish, because let's say it's either heterozygous or homozygous or this was previously- that was homozygous dominant. So, you have a double finned fish like this, if you mate it with a single finned fish, you'd have a 50% chance of it being another single finned fish. But if you mate it with a double finned goldfish, oh, wait, sorry. Let me just test one more thing out, I just realized... Would it be both?	Describing thought process or problem-solving approach	Describes thinking
	Requesting PLA confirmation of thought	Requests confirmation
PLA: Well, if you were to have a double finned goldfish, then-		
Sean: No, it wouldn't be both. Because if it's a double finned goldfish, then they would have 0% chance of it producing a- there's no way to figure out whether it's heterozygous or homozygous.	Correcting own thinking, explaining why thinking is correct	Self-correction Conceptual explanation
PLA: Exactly, yeah.	Validating student's thinking	Validates
Sean: Because it would all produce double.	Continuing explanation	Elaborates
PLA: Exactly.	Validating student's thinking	Validates
Sean: Okay, so it has to be single finned.	Confirming idea	Elaborates
PLA: Yeah.	Validating student's thinking	Validates
Sean: Because that allows you to see whether that allows for a 50% chance for it to be a single finned fish.	Continuing explanation of problem-solving approach	Elaborates

I started developing codes for both PLAs and students inductively, such that I attempted to open code each turn by describing what the speaker was doing with their turn (e.g., asking a question, explaining a concept). I initially coded five transcripts across the three groups in this manner. Once I felt that I had reached saturation and was not encountering any new action codes, I turned to the literature to refine the codebooks for PLAs and students separately.



ICAP framework (Chi & Wylie, 2014)

Passive behaviors: students receive information
Active behaviors: students receive information, identify, and recall background knowledge
Constructive behaviors: sharing ideas, posing and answering questions, generating understanding
Interactive behaviors: students taking turns and building on ideas; collective sense making

PLA practices: cognitive strategies and peer leader verbal behaviors (Ferrari et al., accepted; Kulatunga & Lewis, 2013)

Student learning: instructional discourse and collaborative interactions (Repice et al., 2016; Menekse & Chi, 2019)

Figure 3.2: Conceptual framework that guided codebook development for PLA and Student action codes.

The PLA codebook was informed by previous research I had conducted on the strategies PLAs use to facilitate student learning (Ferrari et al., accepted). In that study, I found that PLAs used three types of cognitive strategies to help students build understanding: asking guiding questions, eliciting student thinking, and providing alternative explanations. While analyzing the transcripts from this study, I observed PLAs utilizing these strategies frequently, but they didn’t account for all PLA actions in their interactions with students. I noticed that the PLAs used other behaviors like clarifying, validating, and offering suggestions to mediate their interactions with students, which was in alignment in previously reported peer leader verbal behaviors by

Kulatunga and Lewis (2013) and instructional discourse described by Repice et al. (2016). Ultimately, I constructed the final codebook of PLA practices abductively, in that I initially created codes from the data and refined it using literature on peer leader discourse. The resulting codebook is presented below, including descriptions for each code (Table 3.7).

Table 3.7

Codebook for PLA Practices

Practice	Action codes	Description
Informing	Provides information	Provides explanation, procedural or factual information, gives answer
	Clarifies	Non elaborate clarifying response
Probing	Elicits student thinking	Asks student to share thinking or problem-solving approach
	Requests inference	Asks question that requires student to make an inference
	Probes for reasoning	Asks students to justify or explain their thinking
Guiding	Asks guiding question	Asks questions about background info to guide student thinking
	Challenges student	Disagrees with student or presents conflicting information
	Orients thinking	Makes suggestion or alerts students to relevant information
Mediating	Validates	Confirms student thinking, idea, or problem-solving approach
	Revoices	Restates or asks student to repeat or clarify their thinking

I constructed the codebook for student actions in much the same way I did for PLAs. Codes were initially created by staying close to the data and describing what students were doing in each turn. I then consulted research on student discourse, specifically discourse identified in peer-led science learning that was related to conceptual explanations and collaborative knowledge building (Halmo et al., 2022; Menekse & Chi, 2019; Repice et al., 2016). I observed that students were asking a lot of questions and articulating their thinking about a problem. In some cases, students would correct their own thinking or challenge a peer's idea. Similar to the PLA codebook, the student codebook was constructed abductively, using both the data and prior research to generate codes that described actions students took in their interactions with PLAs to learn. The resulting codebook is presented below (Table 3.8), including descriptions for each action code.

Table 3.8

Codebook for Student Learning

Action code	**Description**
Conceptual explanation	Gives a reason or accounts for something, sense making
Describes thinking	Articulates thought process or problem-solving approach
Contributes idea	Initial idea; Non elaborate response to peer or PLA
Accepts	Accepts, agrees, or repeats peer or PLA statement
Elaborates	Finishes or adds to own, peer or PLA statement
Self-correction	Corrects or clarifies own thinking or problem-solving approach
Challenges	Confronts or disagrees with peer statement
Identifies confusion	States what is confusing or what isn't understood
Requests clarification	Seeks to clarify idea, confirm thinking or problem-solving approach
Requests information	Asks for explanation, procedural or factual information

All PLA-student interactions were coded using a turn-by-turn approach to provide a fine grain analysis of how their interaction proceeded in the moment. I then considered the interaction as a whole, rereading the exchange to get a sense of what was happening globally. Examining the interactions in this way, along with the turn-by-turn codes, illuminated exactly what students were doing in their communications with each other and with the PLA, and what the PLA was doing in response. This allowed me to characterize the PLA-student interactions using the Interactive-Constructive-Active Passive (ICAP) framework (Chi & Wylie, 2014). The ICAP framework developed by Chi and Wylie (2014) offers a hierarchical organization of observed student behaviors that may mediate learning through the cognitive processes and activities utilized in each mode. In the passive mode, students are receiving information but do not do anything with that information. Students in the active mode manipulate the information they receive, perhaps by copying notes or answering questions using the information provided. Next, students engaged in the constructive mode are generating new knowledge by using information that was provided and applying or synthesizing it. In the interactive mode, two or more students are co-constructing knowledge by building off one another's ideas and questions.

The types of codes present were useful in determining the nature of the interaction. For example, an interaction with more frequent PLA codes, particularly those related to informing, were indicative of more Passive student behaviors. Interactions that included a lot of student questions, were considered Active or Constructive depending on the nature of the questions and what students did with the PLA's response to their questions. Lastly, an interaction with considerable back and forth between students, with their ideas building on one another or replying to each other's questions, suggested an Interactive interaction.

The ICAP framework is a useful approach for characterizing overt student behaviors that reflect the overt cognitive processes they are engaged in and suggests that these behaviors and the associated processes can be differentiated (Chi & Wylie, 2014; Chi & Menekse, 2015). It has been found that the Constructive and Interactive modes provide the highest level of learning compared to the Active and Passive modes (Chi, 2009), as students go beyond the information received to build their own understanding of it, either independently or collaboratively. Although I was most interested in these more generative modes, I chose to include all modes in my analysis, as I wanted to understand if and how PLA actions contributed to student engagement in different cognitive processes observed in each mode.

To characterize each interaction, I specifically looked at what the students were doing, both in their discourse with the PLA and with each other. In Passive interactions, students were listening as the PLA provided information and the students accepted that information without further questions or contributions. Active interactions included more contributions from the student(s), such that a student would describe their thinking, request clarification, or recall background information in response to a PLA question. Students did not go beyond the material presented on their worksheet or provided by the PLA in Active interactions. In Constructive interactions, the student(s) constructed their understanding of the information by asking questions, explaining their thinking, and making self-corrections as the PLA guided their sense-making. Constructive interactions only occurred between one student making substantial contributions with a PLA. Interactive interactions were those that included two or more students engaged in constructive behaviors to co-construct their understanding. In this mode, students engaged in collective sense-making by asking and answering each other’s questions and explaining, expanding on, or challenging each other's ideas as the PLA mediated their discussion. Table 3.9 provides a description of how each level of ICAP was applied in this study.

Table 3.9

Application of ICAP Framework to characterize PLA-student interactions

Mode of Engagement	Description of actions observed in PLA-student interaction
Passive	PLA providing information and student accepting
Active	PLA and student engaged in dyadic dialogue, with PLA asking guiding questions and student contributes ideas by recalling information or background knowledge Student describes thinking or requests clarification and PLA validates or clarifies
Constructive	PLA and student engaged in dyadic dialogue, with PLA questioning and probing student thinking and student describing thinking, explaining, elaborating or questioning to construct understanding Student describes their thinking or explains and self-corrects, PLA guides sense-making
Interactive	PLA and students engaged in constructive, collaborative dialogue, with student ideas building on each other, answering questions, challenging ideas and PLA guiding interaction

In addition, I also gave each PLA-student interactions an Interaction Quality Score (IQS) that I adapted from Menekse and Chi (2019). Interactions were given a score from 0 to 3 to rate the level of interaction among students while the PLA was present. In using the ICAP framework to classify interactions, only a portion of them were considered Interactive, despite the inherently collaborative nature of the learning task. Because I wanted to explore the quality of the interaction between students, even for those not considered Interactive, I applied the additional

IQS metric. The unit of focus was substantive contributions made by students during their interaction. I considered student contributions to be substantive if they meaningfully contributed to the discussion by not only offering new ideas, but also clarifying or expanding on their peer's contributions. Interactions were given a 0 if there were no substantive contributions made by the student(s). A Low Quality interaction (score = 1) was one in which only one student contributed substantive ideas and there was little discussion among students in the group. For example, other students may accept their peer's contribution with no challenge, elaboration, or question; or one student may reach a conclusion with no contribution from other students. Medium Quality interactions (score = 2) included one student contributing substantive ideas, while other students in the group have varying levels of collaboration. For example, student contributions may be made independently of their peers' or one student may reach a conclusion with less contribution from others in the group. A High Quality interaction (score = 3) was one in which two or more students made substantive contributions in collaboration. For example, two or more students contributed ideas and elaborated, challenged, or questioned their peers' statements. In High Quality interactions, student's contributions built off one another and there is a shared line of reasoning as conclusions are co-constructed.

RQ2. How do student engagement and group dynamics during PLA interactions mediate performance?

As I listened to the audio recordings and read through the transcripts, I noticed a discernable pattern within the three groups, such that each had a primary, secondary, and tertiary contributing student. I considered primary students as those who contributed the most to the interaction, both with the PLA and with their peers. Secondary students made considerable contributions, (often in response to the primary student though not always), but not as many as the primary student. The tertiary student made the least contributions and in one group, barely spoke during the interactions. I observed this pattern in each of the three groups. Across groups, each had a unique dynamic between the primary and secondary student, such that in Group 1 they worked mostly independently of one another, in Group 2 the primary student dominated all discussions, and in Group 5 they frequently debated ideas and worked collaboratively.

To explore if my observations had any implications for student performance, I examined their performance on individual exam questions that corresponded to worksheet questions. I chose to only include these questions, rather than all questions on the unit exam, as they were representative of the potential learning that occurred during the PLA-student interactions. In addition, I compared patterns in performance and group dynamics to groups' ICAP classifications and Interaction Quality Scores. To do this, I tallied the number and length of Passive, Active, Constructive, and Interactive interactions for each group. I also calculated the percent of each type of interaction based on the total number of interactions each group had. For the interaction quality scores, I tallied the number of 0, 1, 2, and 3 interaction scores and percent of each for all groups. Finally, I cross-tabulated the ICAP characterizations and IQS scores for each groups' interactions to further explore the nature of students' participation in PLA interactions. This data was used to consider how individual student engagement and group dynamics during PLA-student interactions might mediate student performance.

CHAPTER 4

FINDINGS

In this chapter, I share the findings to Research Questions 1 and 2, which explored how PLAs can facilitate student knowledge building while students work collaboratively and how student engagement and group dynamics during PLA interactions mediate performance, respectively. Through my analysis, I found that student behaviors vary considerably in their interactions with PLAs and students' level of engagement is reflective of the nature of the interaction. Students that engaged in generative interactions showed sense-making behaviors related to knowledge building and, in some cases, knowledge sharing. On the other hand, students that accepted information or stated information without applying it in some way, were engaged in Passive and Active interactions, respectively. Furthermore, the more Interactive a group was during their PLA interactions, the more all students in that group benefitted. Students in groups with lower interaction quality, Active interactions had the lowest performance of all groups. Overall, higher levels of student engagement in discussion with peers and with the PLA appeared to mediate student performance. I posit that both the group's level of engagement and an individual student's participation in their group's interactions with PLAs mediate student performance and may support their learning.

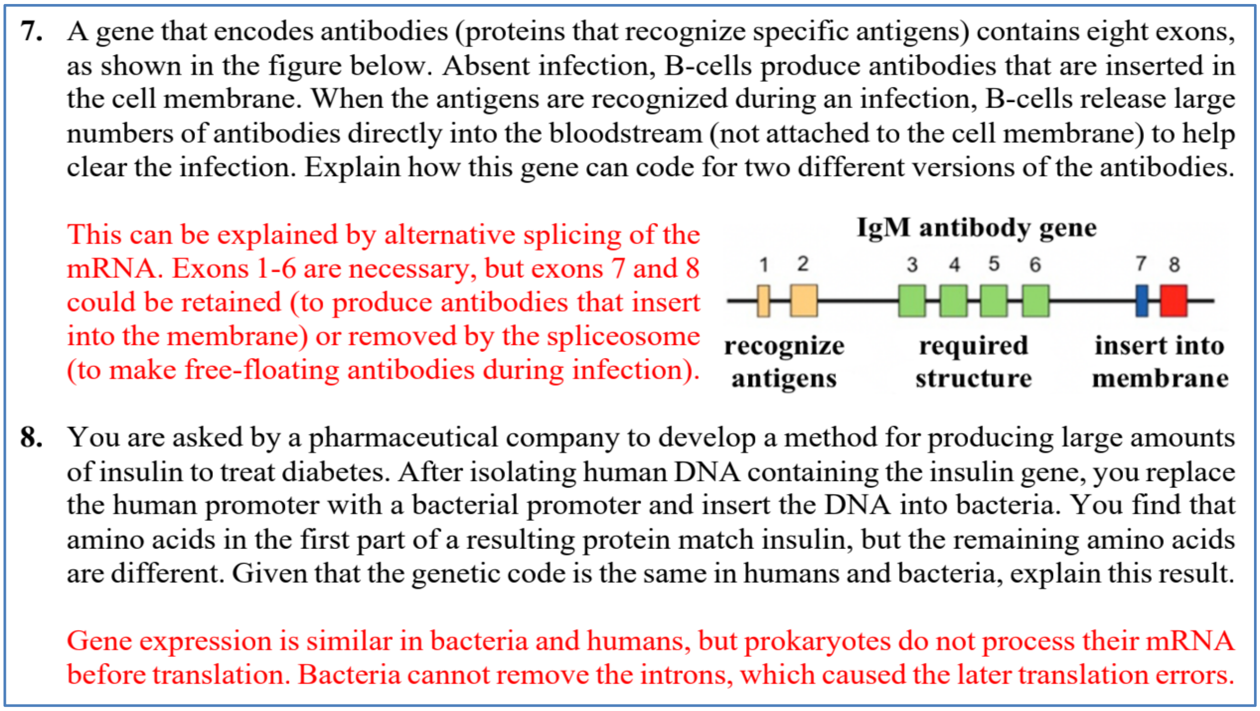
Research Question 1: In what ways do PLA practices facilitate student knowledge construction while students work collaboratively in groups?

To illustrate PLA-student interactions that were classified as Passive, Active, Constructive, or Interactive, I present excerpts for each ICAP mode below. Each excerpt is labeled by 1) the group number and 2) the recording session number. To provide context for the discussion, a snapshot from the answer key showing the worksheet question and answer that is being considered is included above the excerpt. Following the excerpt, I provide a narrative that describes the specific interaction, articulating how the turn-by-turn codes relate to the ICAP behaviors the student(s) showed, and explicitly identify how the PLA facilitated that interaction. There were multiple ways in which each type of interaction could play out, so multiple examples of Active, Constructive, and Interactive interactions are presented below. Only one Passive interaction is included as this mode does not involve substantial contributions by the student(s).

4.1 PLA-Student Interaction ICAP Characterizations

Passive interactions

These interactions were identified as those in which students were seeking confirmation of their answer and the PLA confirmed, or where the PLA explained a question or suggested how to approach a problem and the students accepted. In Passive interactions, students did not provide any substantive comments, they accepted information provided by the PLA.



7. A gene that encodes antibodies (proteins that recognize specific antigens) contains eight exons, as shown in the figure below. Absent infection, B-cells produce antibodies that are inserted in the cell membrane. When the antigens are recognized during an infection, B-cells release large numbers of antibodies directly into the bloodstream (not attached to the cell membrane) to help clear the infection. Explain how this gene can code for two different versions of the antibodies.

This can be explained by alternative splicing of the mRNA. Exons 1-6 are necessary, but exons 7 and 8 could be retained (to produce antibodies that insert into the membrane) or removed by the spliceosome (to make free-floating antibodies during infection).

8. You are asked by a pharmaceutical company to develop a method for producing large amounts of insulin to treat diabetes. After isolating human DNA containing the insulin gene, you replace the human promoter with a bacterial promoter and insert the DNA into bacteria. You find that amino acids in the first part of a resulting protein match insulin, but the remaining amino acids are different. Given that the genetic code is the same in humans and bacteria, explain this result.

Gene expression is similar in bacteria and humans, but prokaryotes do not process their mRNA before translation. Bacteria cannot remove the introns, which caused the later translation errors.

Figure 4.1: Snapshot of the answer key for worksheet from session 1, including the questions and answers for items 7 and 8.

Excerpt 1.1 (Group 1, Session 1):

62:29

Speaker	**Turn**	**Action code**
PLA	Yeah, I can explain eight. So, prokaryotes don't process their mRNA, so that means that they don't know to get rid of introns. But this was human DNA so it has introns, but then bacteria didn't get rid of it, so then it's going to try and pull those introns to amino acids.	Provides information
Tori	Did you say that was for eight?	
Laura	Yeah, it's for eight. You're right, sorry, I just wasn't looking.	
PLA	Just remember that. Prokaryotes don't process RNA.	Provides information
Tori	What about seven?	
PLA	For seven, that one's saying it's about alternative splicing, so you can get rid of the seven and eight part.	Provides information

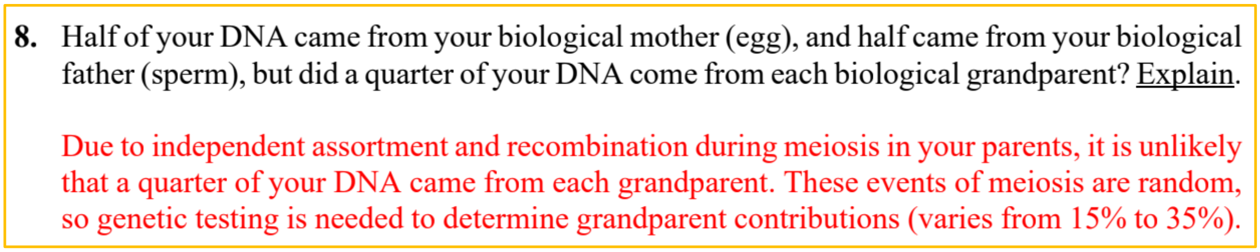
Laura	Okay.	Accepts
PLA	Because then that will still make a gene that works. It's still going to make the structures and the recognize antigens, but the antigens will either insert into the membrane, or they won't. So that's about how you can take out different protein genes and make them new genes.	Provides information

63:09

Narrative: In this Passive interaction, the PLA provided information by explaining what two of the worksheet questions mean and giving students the background information needed to answer the questions. The students, Tori and Laura, accepted the information and did not make any substantive contributions to the conversation.

Active interactions

These interactions were characterized as those in which student contributions did not go beyond the content presented, such that there was no application of knowledge, reasoning, or sense-making. In Active interactions, students described their thinking or approach to a problem and the PLA confirmed it. When students shared an incorrect line of thinking, the PLA may have responded by asking guiding questions to have the student recall information or orient their thinking to steer students in the correct direction. Moreover, the PLA may have responded by providing information which the students accepted without any substantive questions, elaborations, or contributions (Excerpt 1.3).



8. Half of your DNA came from your biological mother (egg), and half came from your biological father (sperm), but did a quarter of your DNA come from each biological grandparent? Explain.

Due to independent assortment and recombination during meiosis in your parents, it is unlikely that a quarter of your DNA came from each grandparent. These events of meiosis are random, so genetic testing is needed to determine grandparent contributions (varies from 15% to 35%).

Figure 4.2: Snapshot of the answer key for worksheet from session 3, including the question and answer for item 8.

Excerpt 1.3 (Group 1, Session 3):

38:00

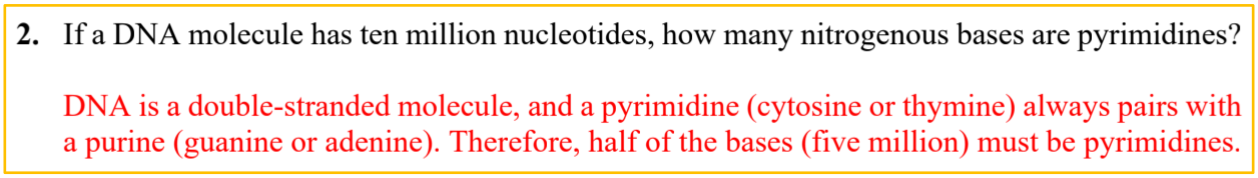
Speaker	Turn	Action code
Kayla	Can you explain eight to us please?	Requests information
PLA	What do you guys understand from it so far? Or like, what have you gotten so far?	Elicits student thinking
Laura	My answer, that I'm not sure about, would be that no, you don't necessarily have a quarter of your grandparents DNA. Just because half of your DNA comes from your mother, doesn't mean that it corresponds to your grandparents DNA. She has all her DNA, and you grab half of it, but it could be that that's a quarter, your grandma's a quarter, your grandpa. Or it could be that it's a different proportion.	Conceptual explanation
PLA	Yeah. Yeah. And think about why it could be a different proportion, you're definitely on the right track. But why could, you're definitely gonna get half from your mom half from your dad. That's set, like you're saying, but why could it vary between how much you'd get from your grandparents? Like you could get, is it 15, or you could get like 30%?	Validates, Asks guiding question
Laura	Is it because of crossing over, or?	Contributes idea
PLA	Yeah, not exactly crossing- I think you're on the right track. But what other ways can you provide variation? How do we provide variation genetically?	Validates, asks guiding questions
Laura	Oh, what is it like recombination, is that it? Recombination?	Contributes idea
PLA	Yes. And what else?	Asks guiding question
Kayla	Fertilization	Contributes idea
Laura	Random like…	Contributes idea

PLA	Think about the way your chromosomes can line up during, I think it's metaphase, like that term that determines the different ways we can line up during metaphase.	Orients thinking
Laura	Yeah, I'm trying to, that's what I'm thinking of, but I can't remember-	
Kayla	Independent assortment?	Contributes idea
PLA	Yeah, yes.	Validates
Laura	There we go, thank you.	
PLA	So with those two, you said recombination, you said independent assortment. That's why it could vary, what you were saying before that's why it's not set in stone. You're gonna get exactly 25 I mean, hypothetically you could. But that's like…	Provides information
Laura	That's rare	Elaborates
PLA	Yeah, so you could get like 15% you could get 30, it just really depends on how your chromosomes independently assort and undergo recombination.	Provides information
Laura	Okay, perfect. Thank you.	

40:12

Narrative: The PLA began this interaction by eliciting student thinking, and Laura responded by explaining her answer to the worksheet question about DNA inheritance. The PLA then tried to orient the group's thinking and asked guiding questions to help them understand why Laura's answer was correct. This created a "call and response" type of interaction where Kayla and Laura recalled key terms like "independent assortment" and "recombination" but did not describe how they influence DNA inheritance patterns. It was the PLA who did more of the intellectual heavy lifting by providing information to explain how the terms elicited from the students supported Laura's answer. While the students made contributions to the interaction, their statements did not contribute to any sense-making as the ideas they contributed were limited to recalling background information. Once the students offered the correct answer, it was the PLA who then provided information by explaining the underlying concepts of independent assortment and recombination.

Interactions were also considered Active when PLAs explained a concept or how to approach a problem and students contributed some ideas, but none that went beyond recalling background information. Lastly, interactions were considered Active when a student requested clarification of their thinking and the PLA clarified or provided information with no substantive follow up contribution by the student (Excerpt 5.1).



2. If a DNA molecule has ten million nucleotides, how many nitrogenous bases are pyrimidines?

DNA is a double-stranded molecule, and a pyrimidine (cytosine or thymine) always pairs with a purine (guanine or adenine). Therefore, half of the bases (five million) must be pyrimidines.

Figure 4.3: Snapshot of the answer key for worksheet from session 1, including the question and answer for item 2.

Excerpt 5.1 (Group 5, Session 1):

3:11

Speaker	Turn	Action code
Farrah	Okay, so there's two pyrimidines for DNA. It's cytosine and thymine. So C and T, has 10 million nucleotides. Oh, 50%. Oh wait, no, no, no. So 50% of 10 million, would be like, like 5 million? Is that wrong?	Contributes idea, Self-correction, Requests clarification
PLA	Do you want to explain that? 5 million.	Elicits student thinking
Farrah	So I'm thinking that, you know, cytosine goes with guanine, thymine goes with adenine, you know that these are going to make up… okay, so whatever amount you have here you have to have the same amount of this.	Describing thinking
PLA	Mhmm	Validates
Farrah	So the pyrimidines, these are the pyrimidines.	Elaborates
PLA	Mhmm	Validates
Farrah	So it's just going to be like half.	Elaborates

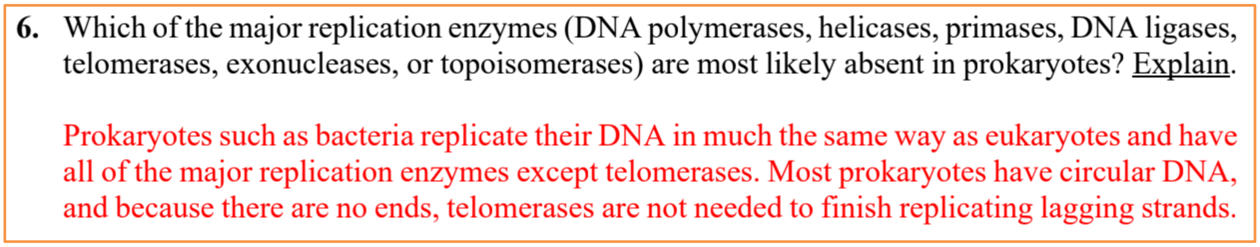
Peyton	Yeah.	Accepts
PLA	Yeah, you're right. Basically, yeah, it's half and half because of the double structure, the double helix structure of DNA. So you can figure that out.	Validates, Provides information

4:19

Narrative: This interaction began with Farrah offering an answer to the worksheet question about DNA nucleotide composition but then realized she may be wrong and requested clarification. The PLA asked her to explain her thinking and Farrah described the reasoning for her answer with some elaboration. The PLA validated Farrah's answer and expanded on her thinking by providing additional information about DNA structure. While Farrah did make substantive contributions by describing her thinking, she did not engage in any sense-making as this interaction was mostly about checking the correctness of her answer and accepting the PLA's explanation.

Constructive interactions

These interactions were characterized by the presence of student sense-making, reasoning, or knowledge application. While interacting with the PLA, students made substantive contributions such as asking questions, elaborating on their own or another's idea, self-correcting their own or challenging a peer's idea, and explaining their thinking. In many cases, Constructive interactions started with the student describing their thinking and the PLA either probing for reasoning, asking guiding questions, or providing information to which the student responded with an idea or question. Constructive interactions only included one student substantively engaged in sense-making, even if multiple students were making contributions to the interaction. When multiple students were contributing during constructive interactions, their contributions were not in response to one another, but to the PLA, or they were just accepting a peer's idea (Excerpt 2.2).



6. Which of the major replication enzymes (DNA polymerases, helicases, primases, DNA ligases, telomerases, exonucleases, or topoisomerases) are most likely absent in prokaryotes? Explain.

Prokaryotes such as bacteria replicate their DNA in much the same way as eukaryotes and have all of the major replication enzymes except telomerases. Most prokaryotes have circular DNA, and because there are no ends, telomerases are not needed to finish replicating lagging strands.

Figure 4.4: Snapshot of the answer key for worksheet from session 2, including the question and answer for item 6.

Excerpt 2.2 (Group 2, Session 2):

35:01

Speaker	Turn	Action code
Sean	Okay, so you know how you have RNA primases where, you know, we have RNA primers to actually start that DNA replication. That's what starts it. Then after the RNA primase has started the replication and starts to replicate, then where the RNA primers are, you also have to replicate the DNA there. Right? Because that hasn't been replicated yet. Yeah?	Conceptual explanation
Gina	Yeah. So then-	Accepts
Sean	That's where the exonuclease comes in. It takes away those RNA primases, then the DNA polymerase actually replaces the missing nucleotides. And then, I don't know what it means by catalyze the last bonds, but it just catalyzed the last bonds.	Conceptual explanation, identifies confusion
PLA	Wait, one thing, that was all great. Catalyze the last bonds, that's the ligase.	Validates, clarifies
Sean	What does that mean?	Requests information
Gina	Does it close it back?	Requests clarification
PLA	The ligase is the enzyme- there's the little break. So you have to connect that and that's what ligase does, so don’t forget about that.	Provides information
Sean	Like break between where the RNA primers were?	Requests clarification
PLA	Were, [G: Oh, the lagging strand] and then build it back, and then after it's built, polymerase can't connect it. So that's what the ligase-	Provides information

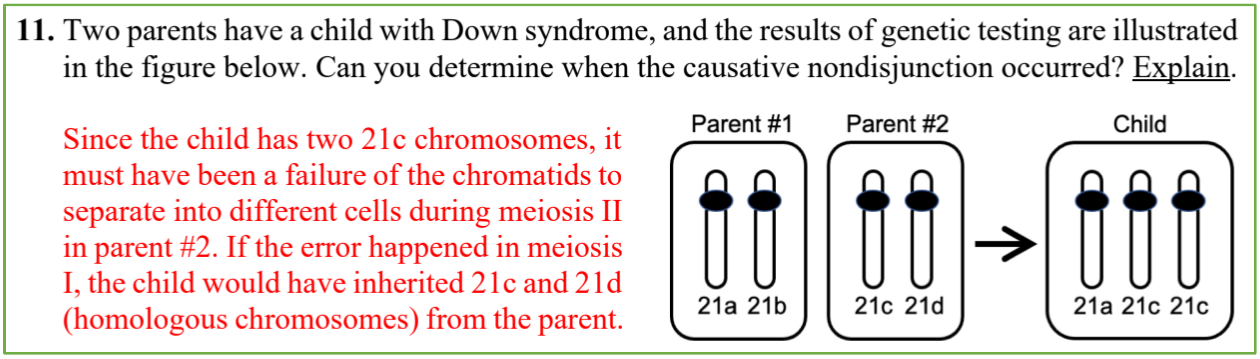
Gina	So for prokaryotes, do they have lagging strands?	Requests clarification
PLA	They, eh, no, I mean, okay, it's not necessarily the lagging strands. I think you're on the right track. Um. What are you thinking?	Challenges, elicits student thinking
Gina	Like, okay, I remember in the picture on the slide, it like showed that prokaryotes only have like one loop for their replication	Describes thinking
PLA	Yeah, they're circular.	Validates
Gina	So that means like, it doesn't need.. it doesn't need to go in different places. Like, how we have a lagging strand.	Elaborates
PLA	Yeah, I think they still have a lagging strand because I'm pretty sure there are still two. I don't think it's single stranded. But there's a protein, or an enzyme that we need because we have linear DNA.	Provides information
Sean	Because we have what?	Requests clarification
PLA	Because we have linear DNA. And prokaryotes have circular DNA.	Clarifies
Sean	They do?	Requests clarification
PLA	So that's important to think about.	Orients thinking
Sean	We have.. is it.. helicase?	Requests clarification
PLA	No, they still have to separate.	Challenges student
Sean	Unbind, separate.	Accept
PLA	Yeah, so they do- they are double stranded.	Clarifies
Sean	Oh, wait, telomerases.	Contributes idea
Gina	Oh, I don't know what that-	
Sean	That's like at the end, what do they actually do?	Requests information
PLA	So at the end of our DNA, we have telomeres, and they're just repeating nucleotides that don't really mean anything.	Provides information
Sean	Like, it's like the tag at the end.	Elaborates
PLA	Yeah, well… not exactly. They're like, they're nucleotides, but they're just repeating. And they don't really code for anything, [S: Okay] but they help keep the structure of the chromosomes and stuff. And so the lagging strand, remember how you learned that it can't get to the end, because there's not that- it has to take away the RNA and there's nothing there to	Challenges student Provides information

	build it back. So the telomerase helps to add on, like a little sequence at the top, so then it can build from that. And I think he explained it, just know that the telomerase helps to lengthen the lagging strand that couldn't be built. So we said that prokaryotes have circular DNA, right? And circles don't have ends. So there's no end that's going to be shorter, it's just going to build all the way up to the start.	
Gina	Oh. Okay.	Accepts
PLA	Does that make sense?	
Gina	Yeah that-	
Sean	So okay wait, so telomeres are just- those are like the unnecessary just repetitive nucleotides? Right?	Requests clarification
PLA	Yeah.	Validates
Sean	And every time DNA replicates, like, that shortens the DNA? in a sense?	Requests clarification

38:53

Narrative: This Constructive interaction began with Sean explaining his conception of how enzymes work in DNA replication. The PLA stepped in to clarify once Sean identified a gap in his knowledge, which led to a series of questions from Sean and Gina. The PLA initially responded by providing information but then changed course and prompted Gina to explain her thinking on the difference between prokaryotic and eukaryotic DNA. Sean suggested an enzyme that may be absent in prokaryotes. The PLA responded by challenging his idea and clarified why that's not the correct answer. Sean offered a second enzyme, and then requested information to understand why it is the appropriate answer. The PLA provided information about the nature of DNA telomeres, and Sean clarified his thinking by describing it in his own words to solidify his understanding. Notably, Gina did not contribute to reaching this conclusion. Because only one student was involved in sense-making, the interaction was Constructive rather than Interactive.

In cases where a PLA provided information or explained how to approach a problem, students engaged in Constructive behaviors would contribute ideas and elaborate on the PLAs statement or request clarifications to clarify their understanding. These Constructive interactions were scaffolded in that the PLA used a variety of actions to facilitate student sense-making, such that student responses went beyond the content and there was an intentional effort to build understanding (Excerpt 5.3).



11. Two parents have a child with Down syndrome, and the results of genetic testing are illustrated in the figure below. Can you determine when the causative nondisjunction occurred? Explain.

Since the child has two 21c chromosomes, it must have been a failure of the chromatids to separate into different cells during meiosis II in parent #2. If the error happened in meiosis I, the child would have inherited 21c and 21d (homologous chromosomes) from the parent.

Figure 4.5: Snapshot of the answer key for worksheet from session 3, including the question and answer for item 11.

Excerpt 5.3 (Group 5, Session 3):

47:56

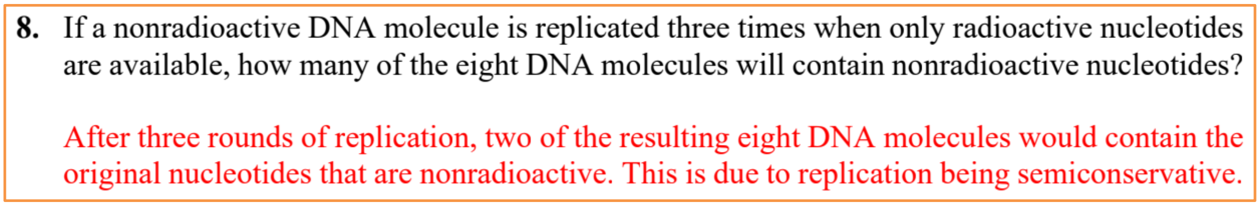
Speaker	Turn	Action code
PLA	I think it might be good to kind of draw out the process.	Orients thinking
Jamie	Do you have that?	
PLA	No, I do not have it drawn out. But for the most part, you can kind of see, think about what would have to happen for you to get these, like, we have two copies of 21 C? And then one copy 21 A.	Requests inference
Farrah	So, in the mom's cell and then you have the dad cell. And there's two chromosomes in each, so it's homologous or whatever. [PLA: Yeah] This one's A, this one's B, this one's C, this one's D. So for Meiosis one, what's supposed to happen? Is it supposed to be that now you have just the homologous separate, so you have two of A, two of B, two of C, two of D?	Describes thinking Requests clarification
PLA	And they're all kind of in their own cells. Yeah.	Clarifies
Farrah	And so after that, next thing that's supposed to happen is, it is supposed to be AB, AB, CD, CD, or something else? Like this chromosome goes with B and separates and that chromosome goes with D and separates?	Requests clarification

PLA	So, basically with these, it would just split so that it's A and B, because basically paired homologous chromosomes are kind of paired up on size for the most part. So, these would split because you see how in the first parent they have 21 A and then 21 B, one kind of came from their mom and one kind of came from their dad basically. So they would have to split into- basically, so you have your A and then your B chromosome.	Provides information
Jamie	What?	Requests clarification
PLA	Because your homologous is split.	Clarifies
Jamie	So are you saying that the A and B, after they split, it's gonna pair together?	Requests clarification
PLA	What do you mean pair together?	Revoices
Jamie	Are A and B paired together? Or is it just gonna be four different things? Like what are you…	Requests clarification
PLA	So with A and B, it's basically, this whole kind of structure. So your end goal is going to be four cells and then they're all haploid. So the A and the B are just going to separate and then once you get through-	Provides information
Jamie	They'll just be four on their own and they'll just be one in each?	Elaborates
PLA	Yeah, because like, that's when your sister chromatids split. So you get two with B, two with A.	Validates, Provides information
Jamie	So the same thing here happens in Meiosis two because the C doesn't split? Is that what's happening? So it ends up with A then two C's.	Describes thinking
PLA	Yes, that's exactly it. If it happened in Meiosis one, what would you see?	Validates, Asks guiding question
Farrah	You'd see two [with] one A, two [with] one C, two [with] one D.	Contributes idea
PLA	Yes. Yeah. Because that would be like a case where the homologous chromosomes failed to split.	Validates, Provides information
Farrah	Ohhh. Gotcha.	Accepts
Jamie	That makes sense	Accepts
PLA	Yeah. It's really good to draw this out, that's a great strategy just to kind of see where everything's going on.	Orients thinking

51:53

Narrative: In this interaction, Farrah and Jamie asked the PLA for a diagram to illustrate what's happening in the process of non-disjunction, but the PLA encouraged them to draw it out themselves, which they did not do. Instead, Farrah described her thinking about how the chromosomes divide and requested clarification to confirm she was on the right track. The PLA provided information to guide her thinking in the correct direction, which prompted Jamie to ask for clarification about the process. In response, the PLA provided information about how chromosomes split, which Jamie elaborated on, thereby working to build her understanding. The PLA validated her thinking and asked a guiding question to further the group's understanding by distinguishing between Meiosis I and II. Farrah offered an idea, which the PLA validated and explained why it was correct. Farrah and Jamie accepted the PLA's statement and acknowledged that the non-disjunction process made sense to them now. The PLA again suggested that they draw out diagrams when working on problems like this. While both students made substantive contributions in their interaction with the PLA, they were independent of one another, and sense-making was not collective. For this reason, the interaction was Constructive rather than Interactive, as student ideas were not made in coordination with one another and did not build off of each other.

Finally, when provided with information from the PLAs, students engaged in the Constructive mode would go beyond just accepting this information. For example, a student might acknowledge their confusion or knowledge gap when presented with information that conflicted with their understanding. Moreover, a student might be prompted to make a self-correction when the PLA provided information that did not align with their prior thinking (Excerpt 2.2).



8. If a nonradioactive DNA molecule is replicated three times when only radioactive nucleotides are available, how many of the eight DNA molecules will contain nonradioactive nucleotides?

After three rounds of replication, two of the resulting eight DNA molecules would contain the original nucleotides that are nonradioactive. This is due to replication being semiconservative.

Figure 4.6: Snapshot of the answer key for worksheet from session 2, including the question and answer for item 8.

Excerpt 2.2 (Group 2, Session 2):

59:05

Speaker	Turn	Action code
Sean	So for this one, you have a DNA molecule and it's replicated. So it's like this, where you have one and you have two and you have four and you have eight at the end, right?	Describes thinking
PLA	Mhmm	Validates
Sean	And the first one, is it like the thing we did in class, the 14 15 N thingy?	Requests clarification
PLA	Yeah	Clarifies
Sean	Okay, but does that mean the first… so how does it-	Requests clarification
Gina	Would it just be half?	Contributes idea
Sean	It would be less than half. It'd be like two or three, right?	Challenges, requests clarification
PLA	Yes.	Validates
Sean	But how? I just guessed, I'm not gonna lie.	Requests information
PLA	Okay, so you're gonna start off with purely nonradioactive. So I guess we'll just kind of use this as, like, purely gray or whatever. And then after first round of replication, this is what it looked like.	Provides information
Sean	It will be- both of them will be 50% radioactive and 50% non-radioactive.	Contributes idea
PLA	I believe so. I believe so. And then after another it would be…	Validates
Sean	You have 50%-	Elaborates

PLA	After another… I believe it would be-	
Sean	Then you would have one is fully radioactive. One is half, two are half, and then one is non. And then you do that again for each and you'd have... you'd have two that are radioactive, you'd have four that are 50. And you'd have two that are non. Is that the answer? To how many of the DNA molecules will contain non-radioactive nucleotides? Oh, wait, is the answer six, then? Okay. Yeah, then I'm stuck.	Describes thinking Requests clarification
PLA 2	All right, so I have a diagram. Okay, so the question is saying that, if a non-radioactive DNA molecule is replicated with a radioactive- so essentially, the main concept here is that it's semi conservative. And so I have here is, the yellow is non-radioactive, and the red is radioactive. And so if it replicates once, you're gonna get four strands of DNA, but then only one of the nonradioactive. Then if you replicate for the third time, you're gonna get eight strands, but then only two of them are nonradioactive. Does that make sense?	Provides information
Sean	Oh, so I did too many steps. So you have- it's more like this, where it's like you have two DNA strands at the beginning.	Self-correction
PLA	Mhmm	Validates
Sean	That turns into four.	Contributes idea
PLA 2	Yeah, because if you have helicase, you know that it's going from this way and this way, and then you essentially have four.	Validates, clarifies
Sean	Okay, and then these two DNA molecules will also replicate into eight in the end.	Elaborates
PLA 2	Yes.	Validates

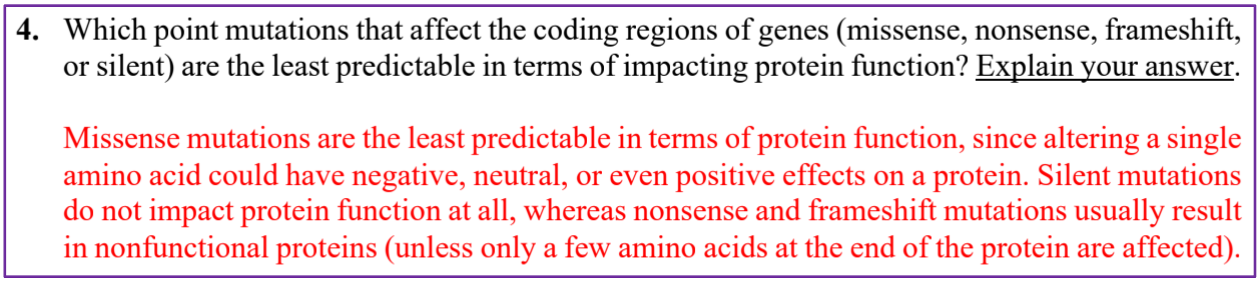
62:39

Narrative: This interaction began with Sean orienting himself to the problem by recalling the discussion of semi-conservative replication of DNA from class, which was followed by Sean and Gina debating the answer to the worksheet question. The PLA confirmed Sean’s thinking, but he admitted he just guessed the answer and was not sure why it was correct. The PLA provided information about how the DNA will look as it replicates, which Sean elaborated on and described his thinking about the process. Upon asking for confirmation of his answer, Sean realized he was stuck so a second PLA shared a diagram to illustrate semi-conservative replication. This prompted Sean to recognize that he did too many steps and he corrected his thinking accordingly. The PLA validated his correction and offered some clarifying information, which helped Sean reach the solution to the question. As Sean was the only student involved in this sense-making exchange with the PLA, the interaction was considered Constructive.

Interactive interactions

These interactions were characterized as such when students were engaged in Constructive behaviors *and* their contributions built off or were in response to one another. In this way, there was collective sense-making where students worked together to co-construct their understanding. When engaged in Interactive interactions, students provided answers to each other's questions, and went beyond acceptance of their peer's ideas by either elaborating on or challenging them.

Excerpt 5.2 illustrates an Interactive interaction from Group 5 that included a lot of disagreement and challenging of peer's statements. The PLA played an integral role in mediating this interaction by clarifying and posing questions to guide the group's thinking.



4. Which point mutations that affect the coding regions of genes (missense, nonsense, frameshift, or silent) are the least predictable in terms of impacting protein function? Explain your answer.

Missense mutations are the least predictable in terms of protein function, since altering a single amino acid could have negative, neutral, or even positive effects on a protein. Silent mutations do not impact protein function at all, whereas nonsense and frameshift mutations usually result in nonfunctional proteins (unless only a few amino acids at the end of the protein are affected).

Figure 4.7: Snapshot of the answer key for worksheet from session 2, including the question and answer for item 4.

Excerpt 5.2 (Group 5, Session 2):

8:46

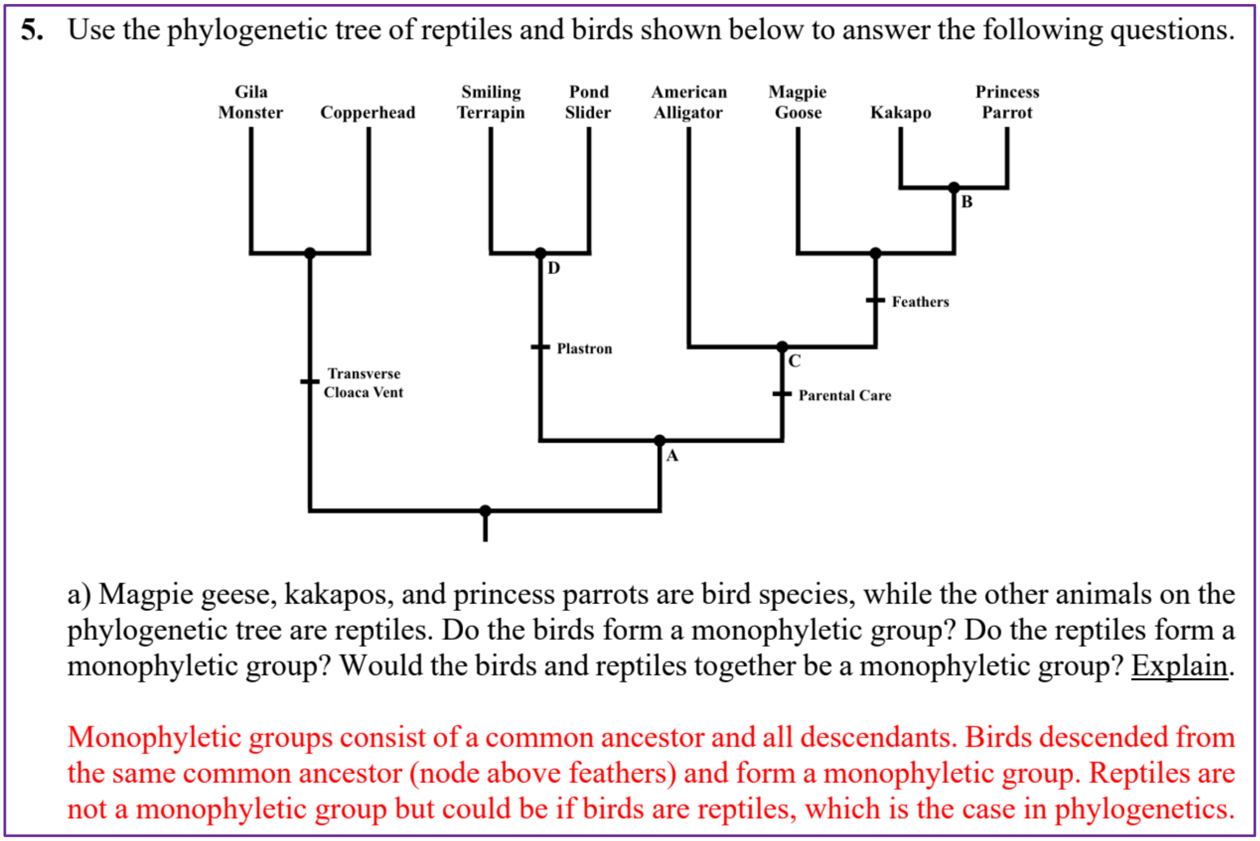
Speaker	Turn	Action code
Farrah	I think it's definitely saying which one is going to be like, this one change is going to, you're not going to tell what's going to happen, it's gonna be a lot of work.	Describes thinking
Jamie	Cause it's like, are these, do these have specific results?	Requests clarification
Peyton	In that case, it'd be silent.	Contributes idea
Farrah	No cause this one is-	Challenges peer
PLA	Why would it be silent? You want to explain that?	Probes for reasoning
Peyton	Uhh, ahh okay. Are the least predictable in terms of, uh because, are silent mutations- it'd be the same amino acid just changing, just say for leucine had UUA and UUG, so say the A and the G flip, you wouldn't be able to tell, you wouldn't be able to predict it, because it's still leucine but um…	Conceptual understanding
PLA	Basically, yeah, actually, you're right with that, because with a point mutation, I mean, yeah. If it switched to a different amino acid, it would be like, we don't know if that protein is going to work or not, [P: Yeah] if it actually might help or hinder. [P: Yeah] But with frameshift, you're not going to get a functional protein.	Validates Provides information
Farrah	So silent is correct? Yes.	Requests clarification
PLA	it's more about like… [F: Explanation?] order.	Orients to key info
Jamie	What does that have to do with predictability?	Requests information
Peyton	Are the least predictable in terms of impacting protein function? Uhh I mean, if a silent mutation happens you wouldn't predict that it would impact the protein function because it'd be the same amino acid. [F: Okay] Is that right? That's how I'm looking at this question, that's worded kind of oddly.	Conceptual explanation, Requests clarification
PLA	Soo, sorry so what you're saying is um, with silent mutations, they're not really silent mutations. Wait a minute. [P: Here I'll just make it easier] But with silent, does anything really change? Does the sequence change?	Asks guiding question
Farrah	So it was frameshift?	Requests clarification
Peyton	No, one singular nucleotide changes, but the amino acid remains the same.	Challenges peer Contributes idea

PLA	Yeah, so how predictable is that?	Asks guiding question
Peyton	What's the question actually, what is it actually asking?	Requests information
Farrah	So the answer is, I'm just gonna put frameshift, that's what I'm writing.	Contributes idea
Peyton	Nope.	Challenges peer
Jamie	What are we asking?	Requests information
Peyton	Yeah, what is it directly asking me to do in this question?	Requests information
PLA	It's asking like basically, if like these mutations occurred, would the protein still be able to do its job? Like to what extent can this protein still work? With frameshift as you said, like…	Provides information
Peyton	It won't work at all.	Contributes idea
PLA	It won't work at all. The silent making it the least…	Validates
Jamie	The silent would be able to work.	Elaborates
PLA	Yeah, but with missense if it changes the amino acid, that might be beneficial…	Provides information
Peyton	It could hinder or yeah.	Elaborates
PLA	Yeah. Or…	Validates
Farrah	So it's the two in the middle.	Contributes idea
PLA	It could be fine. Or it could completely screw everything up. That's right. Yeah. So silent and frameshift [are] pretty predictable. Frameshift, you're not gonna get functional protein. Silent, you're gonna get a functional protein. Missense, you dunno.	Validates Provides information
Farrah	Nonsense you just get stop?	Requests clarification
PLA	Yeah, you're just gonna stop.	Validates

11:54

Narrative: In this Interactive interaction, Farrah, Peter, and Jamie had a lot of debate about what the worksheet question was asking and their different interpretations of the question led to different answers. Farrah was insistent that frameshifts are the least predictable point mutations, but Peter disagreed with her and thought silent mutations would be the least predictable. The PLA asked Peter to explain his thinking, which the PLA validated and explained why frameshift is not the correct answer. Jamie asked how either mutation is related to predictability, which Peter attempted to answer with a conceptual explanation about silent mutations. The PLA validated his thinking and asked the group to consider the predictability of those mutations. This prompted Farrah to insist on frameshifts again as the correct answer, which Peter challenged. Jamie and Peter then ask again what the worksheet question is asking, and the PLA provided information to explain the intent of the question. Jamie and Peter then elaborated on the PLA's description of the different point mutations to reach a final answer. All three students made varying levels of substantive contributions to this discussion, either by asking questions, challenging peer's ideas, or elaborating on the PLA's explanation to collectively build understanding, thereby making this an interactive interaction.

Excerpt 1.5 presents an Interactive interaction where one student responds to their peer's questions and they elaborate on one another's ideas. The PLA facilitated this interaction by first eliciting student thinking and then provided information when necessary to clarify the students' understanding.



5. Use the phylogenetic tree of reptiles and birds shown below to answer the following questions.

a) Magpie geese, kakapos, and princess parrots are bird species, while the other animals on the phylogenetic tree are reptiles. Do the birds form a monophyletic group? Do the reptiles form a monophyletic group? Would the birds and reptiles together be a monophyletic group? Explain.

Monophyletic groups consist of a common ancestor and all descendants. Birds descended from the same common ancestor (node above feathers) and form a monophyletic group. Reptiles are not a monophyletic group but could be if birds are reptiles, which is the case in phylogenetics.

Figure 4.8: Snapshot of the answer key for worksheet from session 5, including the question and answer for item 5a.

Excerpt 1.5 (Group 1, Session 5):

34:01

Speaker	**Turn**	**Action code**
Tori	Can you explain how to read this, please? Just a brief ...	Requests information
PLA	Okay. So number five.	
Kayla	Would the feathers technically be a monophyletic group, or no?	Requests clarification
PLA	So the question is asking do birds form a monophyletic group. So what did you guys think about that or say for that?	Orients thinking, Elicits student thinking

Kayla	Yes?	Contributes idea
Tori	Yeah.	Contributes idea
PLA	And why do you think that?	Probes for reasoning
Tori	The feathers one.	Contributes idea
Kayla	Yeah, because they're all going off the feathers. They all have feathers.	Elaborates
PLA	Yeah, well, because they all come from a common ancestor, so the node would technically be the reason because that node is the common ancestor, so yeah. You're right, birds would be because they all descend from that node above the feathers, which is their common ancestor. And then the second part, it's asking do the reptiles form a monophyletic group.	Validates Provides information, Orients thinking
Kayla	No.	Contributes idea
Tori	This node would be… it wouldn't be C, right?	Requests clarification
PLA	For?	
Tori	For the birds. Which node is it?	Requests clarification
PLA	The one above the feathers.	Clarifies
Tori	So B?	Contributes idea
PLA	Does it say name the node?	
Tori	No.	Contributes idea
Kayla	No it doesn't.	Contributes idea
PLA	Okay, well, it would be the one above the feathers. Yeah, that would be the common ancestor. Does that make sense? Because these are your birds, right? If this is a common ancestor, this one obviously comes from that, right? But then these two also do too because technically, even these go back to that node, they also go back to that node. So that's why the node above the feathers would be the common ancestor for all the birds.	Provides information
Tori	Okay. So for the reptiles-	Accepts
Kayla	Would it be this node right here?	Requests clarification
PLA	You were saying something earlier about the reptiles. What did you say?	Elicits student thinking

Kayla	I said no.	Contributes idea
PLA	Okay, and why did you think no?	Probes for reasoning
Kayla	Because the birds are still kind of going off of it still, so it's not just only reptiles.	Describes thinking
PLA	Yeah, exactly, so unless birds were, for whatever reason, counted as reptiles, which they're not, then since we know they're not, then that means, like you said, they can't be monophyletic. Or reptiles can't be.	Validates Provides information
Tori	So reptiles aren't?	Requests clarification
Kayla	No, since birds are going off of it. And then the last one would be like the last node. The very last node at the bottom of the monophyletic-	Conceptual explanation
Tori	What's the last one?	Requests clarification
Kayla	This one right here.	Contributes idea
Tori	The birds and reptiles togethers (writing)…	

36:40

Narrative: In this interaction, Tori and Kayla were trying to understand how to read a phylogenetic tree in order to determine if birds form a monophyletic group. The PLA asked why the students thought the birds form a monophyletic group and they replied that the feather trait has something to do with it. The PLA clarified that the birds form a monophyletic group because they all descend from a common ancestor, which is why they all have feathers. The PLA then asked the students if reptiles also form a monophyletic group. Kayla answered no, but Tori requested further clarification about the node that illustrates the birds' common ancestor. The PLA provided information to explain this, and Tori started to ask about the reptiles but was interrupted by Kayla asking a question. The PLA asked Kayla to explain why she didn't think reptiles form a monophyletic group and she explained her thinking, which the PLA validated. Tori asked for clarification about the reptiles being a monophyletic group and Kayla provided a conceptual explanation in response. Tori asked Kayla for clarification, and Kayla clarified, allowing Tori to start constructing an answer to the worksheet question. Both Kayla and Tori made substantive contributions to this interaction by asking questions, responding to peer's questions, and elaborating on one another, so the interaction was characterized as Interactive.

I characterized PLA-student interactions as either Interactive, Constructive, Active, or Passive based on the student(s) contributions to the interaction (as identified by the student codes) and how their contributions related to [collective] sense-making. When students only accepted a peer's idea or the information provided by the PLA, the interaction was generally Passive because the student(s) was receiving information and doing nothing else with it. When engaged in Active interactions, students either shared their thinking, asked questions, or recalled background information, but did not take any actions to try and make sense of a concept. It was often the PLA who provided an explanation. The PLA also asked guiding questions, but did not probe for student reasoning or ask students to make an inference that would require them to go beyond the material presented and apply their knowledge.

In the generative modes, Constructive and Interactive, PLA-student interactions were reflective of student sense-making and building understanding. When a student described their thinking, asked questions, self-corrected or expanded on an idea, they were engaged in a Constructive interaction with the PLA. The PLA may have provided some information to the student, but in response, the student used that information in some way, rather than just accepting it, either by elaborating on it or asking another question to try and build understanding. When engaged in an Interactive interaction, two or more students participated constructively such that they responded to one another's ideas, either by elaborating on them, challenging them, or asking questions in response. These interactions were often student-led and driven by a collective attempt to make sense of the concept, while the PLA played a supportive role in guiding the conversation by eliciting student thinking and providing clarification.

In this analysis, I explained how the nature of student(s) contributions to their group's interaction with a PLA is relevant to their level of engagement. Student's behaviors varied from accepting information to asking questions to sharing conceptual explanations, the former being Passive while the latter is Constructive. Some interactions were Interactive when student ideas built off one another and they coordinated their responses to collectively generate knowledge. The PLAs' actions also played a role in the nature of these interactions, as those which prompted the students to explain their thinking, self-correct, or make an inference were more successful in supporting a generative interaction than simply providing information or clarifying without any follow up questions. In the analysis below, I illustrate how the interactive quality of PLA-student interactions relates to student learning.

Research Question 2: How do student engagement and group dynamics during PLA interactions mediate performance?

4.2 Student Engagement, Group Dynamics, and Performance

To explore how a student's level of engagement during their interaction with a PLA may mediate their performance, I considered student performance on exam questions that were written to correspond with the worksheet questions that students completed in groups with assistance from PLAs. I assigned a "Role" to each student in the three groups based on my observations of their level of participation and the nature of their contributions to their group's discussion during their interactions with PLAs. Each student's performance on exam questions that aligned with worksheet questions was calculated by comparing the overall number of aligned questions they answered correctly on the unit exam by the total number of aligned questions (n=47) to find the percent (Table 4.1). Table 4.1 shows the three students' roles in each group and their performance on exam questions that aligned with worksheet questions. Notably, the primary and secondary students in Groups 1 and 5, Laura and Farrah, respectively, performed considerably higher than the tertiary students in their groups, Tori and Jamie, respectively. An exception to this pattern was Group 2, in which the primary student, Sean, performed significantly better than the secondary and tertiary students, Nick and Gina, who had a similar level of performance. Of the three groups, Group 5 had the highest level of performance while Group 1 had the lowest performance overall.

Table 4.1

Student performance on exam questions that aligned with worksheet questions. "Role" indicates participation level and contribution of each student made during group work.

Group	**Student**	**Role**	**Correct Answers (n=47)**	**Performance (%)**
1	Laura	Primary	32	68.1
	Kayla	Secondary	31	66.0
	Tori	Tertiary	24	51.1
2	Sean	Primary	37	78.7
	Gina	Secondary	28	59.6
	Nick	Tertiary	29	61.7
5	Farrah	Primary	43	91.5
	Peter	Secondary	41	87.2
	Jamie	Tertiary	32	68.1

The observed pattern suggests that students who actively participate in their group's interactions with PLAs by making substantial contributions may benefit in their performance. Students who play a tertiary role by less frequently sharing their ideas, asking questions, and responding to their peers appear to perform worse than their peers who are more engaged. Therefore, a student's performance on exam questions that aligned with worksheet questions may be mediated by their level of participation in group interactions with PLAs. I explore this pattern further in the analysis below, which compares the ICAP categorizations and Interaction Quality Scores (IQS) between groups.

4.3 Group Interactions

Across the three groups, Active interactions were the most common, followed by Constructive and Interactive interactions. Passive interactions were the least common. However, the amount of Interactive and Passive interactions was more comparable than Interactive and Active or Constructive interactions (Table 4.2). The Interaction Quality Score (IQS) across groups followed the same pattern, such that most interactions were scored as Low Quality (1) and High Quality (3) interactions were the least frequent, excluding interactions that were scores as No Quality (0) interaction (Table 4.3). Finally, the ICAP characterization and IQS score was cross-tabulated for each group's interactions (Table 4.4). This illustrated that across the three groups, most Active interactions were scored as Low Quality (1), Constructive interactions were of Low (1) and Medium (2) Quality, and Interactive interactions were most of High Quality (2).

Table 4.2

ICAP categorizations of each group's interactions, presented as a raw number and percent of total interactions.

Group	Passive		Active		Constructive		Interactive		Total interactions
	#	%	#	%	#	%	#	%	
1	6	17.1	18	51.4	7	20.0	4	11.4	35
2	5	10.6	14	29.8	26	55.3	2	4.3	47
5	1	3.1	15	46.9	6	18.8	10	31.3	32
Total	12	10.5	47	41.2	39	34.2	16	14.0	114

Table 4.3

Interaction quality scores (IQS) of each group's interactions, presented as a raw number and percent of total interactions.

Group	IQS 0 (None)		IQS 1 (Low)		IQS 2 (Medium)		IQS 3 (High)		Total interactions
	#	%	#	%	#	%	#	%	
1	4	11.4	20	57.1	9	25.7	2	5.7	35
2	4	8.5	24	51.1	18	38.3	1	2.1	47
5	0	0	9	28.1	13	40.6	10	31.3	32
Total	8	7.0	53	46.5	40	35.1	13	11.4	114

Table 4.4

Cross-tabulation of ICAP characterizations and Interaction Quality Scores (IQS) of each group's interactions.

Group	IQS	Passive	Active	Constructive	Interactive
1	**None (0)**	3	1	0	0
	Low (1)	3	11	6	0
	Medium (2)	0	6	1	2
	High (3)	0	0	0	2
	Total interactions	6	18	7	4
2	**None (0)**	4	0	0	0
	Low (1)	1	9	14	0
	Medium (2)	0	5	12	1
	High (3)	0	0	0	1
	Total interactions	5	14	26	2
3	**None (0)**	0	0	0	0
	Low (1)	1	7	1	0
	Medium (2)	0	8	5	0
	High (3)	0	0	0	10
	Total interactions	1	15	6	10

Group 5: This group was the most Interactive and had the most High Interaction Quality Scores (3) out of the three groups. However, although they were the most Interactive of all the groups, almost half of all their interactions were Active, while one third were Interactive (Table 4.2). Moreover, most of this group's interactions were Medium Quality (2), indicating that multiple students participated and contributed to group discourse, but at varying levels (Table

4.3). Finally, two students in Group 5, Farrah and Peter, scored the highest on exam questions aligned with worksheet questions out of all students in the analyzed groups. The third student in this group, Jamie, performed considerably lower than her groupmates, but her scores were the same or higher than five out of six students in Groups 1 and 2. This suggests that although Jamie did not contribute as much as Farrah and Peter to the group discourse, her performance may have been mediated by participating in such an Interactive group.

Group 2: Out of the three groups, this group had the most Constructive interactions (Table 4.2). However, their interactions were most often scored as Low Quality (1) and they had the least High Quality scores (3) of all groups (Table 4.3). Moreover, this group was the least Interactive of all the groups and actually had more Passive than Interactive interactions. The interactions in this group were dominated by one student, Sean, which is consistent with the larger number of Constructive and Low Quality interactions (Table 4.4). This student had higher performance than the other students in his group and this was the only group in which the secondary and tertiary students performed similarly (Table 4.1). This indicates that while Sean likely benefitted from his extensive Constructive interactions with the PLA, Gina and Nick did not. These students contributed significantly less and did not participate much in Sean's discussions with the PLAs. Therefore, it is possible that performance is not mediated for students on the periphery of a Constructive interaction, in which they may only be passively engaged.

*Group 1***:** This group had the most Low Quality interaction scores (1) of out of the three groups (Table 4.3). Within Group 1, more than half of the interactions were Active, while Interactive interactions were the least common (Table 4.2). Similar to Group 2, one student from this group, Laura, dominated most interactions with the PLA. However, another student, Kayla, also engaged in separate interactions with the PLA. This explains why this group had the greatest number of Low Interaction Quality Scores (Table 4.3). Both of these students had a similar level of performance (Table 4.1), which was higher than the third member of their group, Tori, but still lower than students in groups who engaged in more Constructive (Group 2) and Interactive (Group 5) interactions with the PLAs. This is consistent with the notion that Active interactions are less supportive of learning than generative interactions. Moreover, the student who was the least participative, Tori, scored the lowest out of all students across the three groups. This suggests that her passively listening to her groupmates' Active interactions with PLAs provided no meditating benefit to her performance.

In these findings, I illustrate how both the level of engagement (ICAP) and quality of the interaction (IQS) mediate student performance. The observed pattern followed the ICAP framework hierarchy, in which groups that were more Interactive performed better and those that were mostly Active had lower performance. Similarly, groups that had higher IQS performed better than those with lower IQS. Moreover, this trend was consistent for students who were the least participatory in their group's interactions with PLAs. Tertiary students in groups with higher IQS and more interactive interactions performed better than almost all students in groups with lower IQS that were either Constructive or Active. This noteworthy finding suggests that there may be a mediating benefit for students who are less engaged in their group's Interactive interactions with a PLA. However, there does not appear to be any mediating benefit regarding the performance of Passive students in groups that are less Interactive.

Role of the PLA in Facilitating Group Interaction

Regarding the role of the PLA in facilitating student collaboration during their interactions, another pattern can be discerned from the data presented above. Students that contributed substantively to the sense-making dialogue with the PLA performed better on exam questions aligned with worksheet questions than students who did not have a high level of engagement with the PLA, as seen in Group 2. Additionally, students that made substantive contributions while dialoguing with their peers and the PLA performed even higher, as seen in Group 5. The emergent pattern is such that students that engaged in collective sense-making in the presence of PLA had the highest performance, students that engaged in dyadic sense-making with the PLA had medium performance, and students that did not engage in substantive sense-making with or in the presence of PLA had the lowest performance. This indicates that participating in sense-making discussions with both peers *and* the PLA may offer a mediating effect on student performance, rather than participating in one or the other.

CHAPTER 5

DISCUSSION AND IMPLICATIONS

In this dissertation, I investigated how PLAs support student learning, and I used the ICAP framework as a lens for my analysis. The purpose of this study was to understand how PLAs facilitate student knowledge building through interactive discourse, and how student participation in PLA-student interactions relates to student learning. Given the growing implementation of Peer Learning Assistant programs in universities and colleges across the United States, I was eager to go beyond the foundational studies that have assessed *if* PLAs support student learning to explore *how* they do it. I believe that PLAs offer instructors an avenue to help foster student-centered learning spaces and incorporate class activities that prioritize student thinking, reforms that are strongly recommended but difficult to implement without additional instructional assistance. A deeper understanding of what PLAs are doing in their interactions with students in science classrooms is needed to effectively utilize PLAs and strengthen these important peer learning programs. The following research questions were addressed in this study:

RQ1. In what ways do PLA practices facilitate student knowledge construction while students work collaboratively in groups?

RQ2. How do student engagement and group dynamics during PLA interactions mediate performance?

This study was guided by qualitative inquiry using a discourse analysis approach to characterize PLA-student interactions and examine patterns between student engagement and performance in an introductory biology course. The key conclusions from this analysis are identified below and their relevance to prior studies is discussed. I also share the implications of my work in relation to instructor decision-making and PLA pedagogy training to better support student engagement in collaborative learning.

1) When PLAs used informing and mediating practices while interacting with students, students were less engaged in generative learning actions.
2) Students engaged in more generative learning actions when interacting with a PLA that utilized probing and guiding practices.
3) The dynamics of student groups influenced the nature of PLA-student interactions, such that not all students participated in these interactions equally.
4) The nature of student engagement in PLA-student interactions may mediate student performance.

5.1 Discussion of Conclusions

Conclusions 1 and 2: Both students and PLAs engaged in a variety of behaviors during their interactions that were related to the learning task. However, only some of these behaviors were supportive of students' efforts to build understanding. The nature of PLA-student interactions appeared to be guided by a student's intent for initiating the interaction and the way the PLA responded to the student's ideas. PLA practices loosely followed a hierarchical trend (Figure 5.1), such that mediating and informing were more indicative of Passive or Active student learning, while guiding and probing were more facilitative of generative student learning (i.e., Constructive and Interactive).

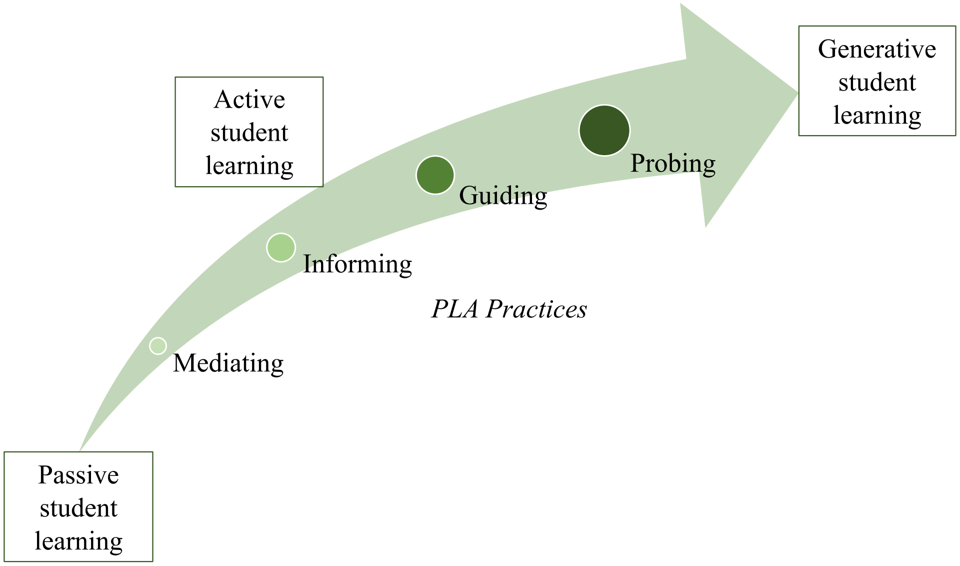


Figure 5.1: Hierarchy of PLA practices that facilitate student learning during PLA-student interactions.

Often, students initiated an interaction with a PLA by asking the PLA to confirm their thinking or problem-solving approach. In other instances, students asked a PLA a question about a course concept or to understand what a worksheet question was asking. The way that PLAs responded to these student inquiries was unique, such that there was no linear or predictable model that I observed. However, what was clear was that the practice a PLA used when responding to students influenced their interaction. For example, when PLAs simply validated a student's thinking without probing them to explain their thought process, the student accepted that validation without engaging in the interaction much further. Evidence shows that when student dyads accepted their peer's ideas without adding anything they did not learn significantly (Menekse & Chi, 2019), suggesting that there is little benefit to student learning by only accepting information provided by a PLA. Moreover, when PLAs responded to a student's question by clarifying with a direct answer rather than redirecting the question to another student, the students passively accepted that information. Similarly, Knight et al. (2015) found that student discussion stopped once PLAs provided reasoning for an answer.

In some Active interactions, PLAs asked students several guiding questions, but those intended to prompt student recall of background information resulted in student knowledge sharing, not knowledge building. While these actions may be useful for confirming that students were on the right track with the necessary information, these interactions did not lend themselves to building student understanding. Guiding questions can be beneficial when used as formative assessment, in which the instructor elicits the student's explicit understanding and uses that information to take action to support the student's learning (Furtak & Ruiz-Primo, 2008). Likewise, short questions can promote student argumentation by eliciting information from students, but further probing is required to prompt student reasoning (Kulatunga & Lewis, 2013). Therefore, it is likely that short questions alone do not contribute to higher-order cognitive processing as additional steps are needed to help the student move beyond information recall. Higher order cognitive skills like application are required to fully understand scientific concepts (Crowe et al., 2008). Active PLA-student interactions included exchanges where PLAs asked prompted information recall or students shared their ideas without follow-up questions from the PLA. Such interactions lacked the constructivist elements needed to support student learning.

Conversely, when PLAs prompted students to explain their thinking or problem-solving approach rather than just confirming it, students had to articulate their ideas. This provided an opportunity for students to monitor their understanding, while also allowing the PLA to follow a student's thought process and identify any errors. This is consistent with PLA pedagogy training, which emphasizes the importance of eliciting student ideas and using them as a bridge to further a student’s conceptual understanding (Gray, 2013). Furthermore, studies about peer learning and metacognition have found that self-explaining is associated with knowledge building language, which was positively correlated with deep learning (Roscoe & Chi, 2008; Roscoe, 2014). This suggests that PLAs engaged students in constructive behaviors when they elicit student thinking. Similarly, when PLAs asked students a question that required them to make an inference or provide reasoning, students had to go beyond the material presented in their notes or on the worksheet and apply their knowledge. These types of “open questions” have been linked with conceptual explanations and reasoning that students do not offer without prompting (Knight et al., 2015; Repice et al., 2016), suggesting that the nature of the PLA’s question influences students’ engagement with constructive learning behaviors. These findings are also supported by a study that examined how instructor questions impact student learning, such that students made more inferences and had higher performance when instructors posed Constructive questions compared to Active and Passive questions (Morris & Chi, 2020).

Interactive interactions were those in which two or more students were engaged constructively, such that their contributions to the discussion were coordinated and built on each other. In these interactions, there was often disagreement between students that they were working to resolve or one student asked questions and a group member responded. Often, the PLA played a supportive role by using a variety of strategies to guide the students’ discussion, including eliciting student thinking, probing for reasoning, clarifying student ideas, and providing information. This instructional scaffolding, in which a peer leader uses a combination of questions and mediating behaviors, has been shown to support learning through reciprocal discourse between the peer leader and student (Kulatunga & Lewis, 2013). Moreover, when guided by peer leaders that use such facilitative practices rather than instructive ones, student groups are more collaborative, in that they elaborate on each another’s ideas and self-monitor the groups’ understanding of a problem (Sawyer et al., 2013).

Unique opportunities for collaborative learning arise when students explain their thinking, as another student may become aware of errors in their own thinking as a result of listening to their peer (Yackel et al., 1991). When PLAs asked probing questions, students had to articulate their thinking, which provided an opportunity for their peers to challenge, question, or elaborate on their idea. Posing questions that require higher-order cognitive skills is more effective at engaging students in the co-construction of answers (Leupen et al., 2020). Moreover, students are more likely to elaborate on their reasoning when one or more students are engaged in constructing an argument (Kulatunga & Lewis, 2013). Therefore, PLAs can facilitate Interactive interactions by asking questions that elicit student thinking and create opportunities for students to respond to their peers’ ideas. Indeed, Repice et al. (2016) found that students rarely engage in conceptual explanations and self-monitoring without prompting from a peer leader, even when students are working collaboratively in groups.

For interactions to be considered Interactive, student contributions had to be Constructive, in that they added something new to the conversation, and there must have been sufficient turn-taking between group members (Menekse & Chi, 2019). Frequent turn taking supports all learners, as students have more opportunity to ask questions and incorporate their peers’ ideas into their own thinking. During Interactive interactions, PLAs allowed students to respond to their peer’s questions and elaborate on their ideas by ceding the floor when necessary, and stepping in to clarify confusion or orient student thinking. In some cases, particularly in Group 5, two students challenged each other’s ideas. The PLA refrained from identifying who was right or giving a direct answer, but rather used guiding practices to help students navigate their disagreement. When provided opportunities for re-evaluation, students are pushed into the Interactive mode as they engage in back-and-forth discussion to identify their confusion and reconcile their prior thinking with the differing perspective of their peer (Leupen et al., 2020).

Conclusions 3 and 4: The three groups that were the focus of this analysis approached their interactions with PLAs in considerably different ways. Each group had a conversation dominating student, a student that played a secondary role in PLA-student interactions, and a tertiary student that contributed to the conversation infrequently. Students' varying levels of engagement in their group's interactions with PLAs may have had a mediating effect on their performance, such that students who were more engaged performed better on exam questions that aligned with practice activity worksheet questions.

There are several reasons why collaborative group work may not support student learning. Hodges (2018) points out that the cognitive load of group processing can undermine the effectiveness of the learning activity. Moreover, the cognitive load of the learning task itself may not lend itself to collaborative group work. However, the instructor of BIO 201, Dr. James, designed the practice activity worksheet to include open-ended, higher order questions that were reflective of the unit exam questions. The worksheet questions were all application based and more difficult than the multiple-choice clicker questions students practice with in class. Additionally, Dr. James wrote the exam questions first and they were frequently informed by his interactions with students, namely what they answered incorrectly on the clicker questions, which concepts they struggled with, and when they used shortcuts to answer clicker questions. He designed exam questions, and the subsequent worksheet questions, to help move students away from algorithmic thinking by requiring them to think about what they were doing. Therefore, the cognitive load of the learning task, the practice activity worksheets, was high.

However, this created an opportunity for students working in groups to layer their complementary knowledge (Hodges, 2018).

Another possible obstacle to effective group collaboration is the social factor. Not all students are natural collaborators and may not display supportive social behaviors such as encouraging ideas and accommodating confusion (Johnson & Johnson, 1999). However, in my observations of the three analyzed groups, this was not an issue and I did not consider any of the groups to be “dysfunctional” in their collaborative efforts. Given that, most groups did have a student who dominated discussion, which has shown to negatively impact the performance of other students in the group (Theobald et al., 2017). The impact of a conversation dominator for each of the three groups is explored below.

Group 1, which included Kayla, Laura, and Tori, had the most Active interactions with PLAs. Two of the students, Kayla and Laura, often engaged in separate discussions with the PLAs to check their own understanding or problem-solving approach to a worksheet question. I found that Tori played a tertiary role in these interactions, as she made less contributions to group discussions and infrequently initiated interactions with the PLAs. Kayla was the secondary student, as she participated in discussion with the PLA and made substantial contributions, but less so than Laura, who I considered the primary student, or conversation dominator. Laura directly engaged with the PLA the most by sharing her thinking, and occasionally spoke on behalf of another student in her group. When Laura was confused, she explained her thinking to her groupmates to work through her misunderstanding. My interpretation of Laura’s interactions with the PLAs is that she seemed to be the most aware of her understanding and the most eager to share her thinking. However, this did not translate into higher performance than Kayla, and Laura’s performance was the lowest among primary students across groups.

Laura’s low performance, and that of her groupmates, may have been due to the nature and quality of their interactions with PLAs. This group’s interactions were mostly Active (51.4%) and least often Interactive (11.4%) in nature. Similarly, more than half of Group 1’s interactions were scored as Low Quality, which was the most across the three groups. Conversely, approximately one third of their interactions were Medium or High Quality, which was the least across the three groups. This group also had the most Passive and No Quality interactions. In summary, Group 1 was the least Interactive and engaged in PLA-student interactions (Figure 5.2). Collectively, these students also had the lowest performance across the groups, which may have been due to the way they interacted with PLAs. Their interactions were mostly Active, consisting of one student interacting with the PLA to confirm their thinking or asking how to approach a problem. This was not a beneficial approach for the student(s) interacting with the PLA, but unsurprisingly, it also did not benefit the tertiary student who might have been passively listening to their peer’s conversation with the PLA. This is consistent with Menekse and Chi (2019), who found that dyads with Low Quality interactions had less learning gains than dyads with High Quality interactions. Moreover, students’ acceptance of information from a peer without following up with a question or elaborating on the idea was correlated with lower learning gains. Accepting as a discourse move is frequently observed in Passive and Active interactions, and there is no meaningful learning gain for the non-contributing partner (Menekse & Chi, 2019).

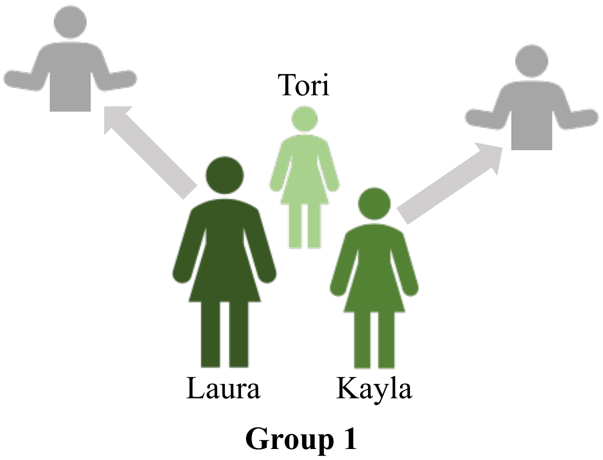


Figure 5.2: Group 1 dynamics, including relative size and color intensity for three students (green) illustrating their level of engagement. Gray arrows show directionality of engagement, such that Laura and Kayla are engaged in interactions with PLAs but not in a Constructive mode, as indicated by the single arrow.

Group 2, which included Sean, Gina, and Nick, had the most Constructive interactions with PLAs. Sean was the most dominant speaker in this group, as he initiated and led almost all conversations with the PLAs. From his contributions, I sensed that Sean really wanted to understand the concepts so he asked a lot of questions, though some of which were a bit tangential to the worksheet questions. There were a few times he admitted to skipping lectures, so it appeared that he used these practice activity exam review days as a chance to learn content he had missed. This group also engaged in the longest interactions with PLAs, which were always a result of Sean's tenacious questioning in an attempt to build his understanding. In contrast, I rarely heard Nick speak in the recordings. For this reason, he was considered the tertiary student. Gina did make some contributions to the PLA interactions, but they were far less frequent than Sean's and less substantial in the sense that her comments were more superficial or procedural, rather than conceptual. I considered her the secondary student, as it appeared that she was engaged in the PLA interactions even though she made far fewer contributions than Sean (Figure 5.3).

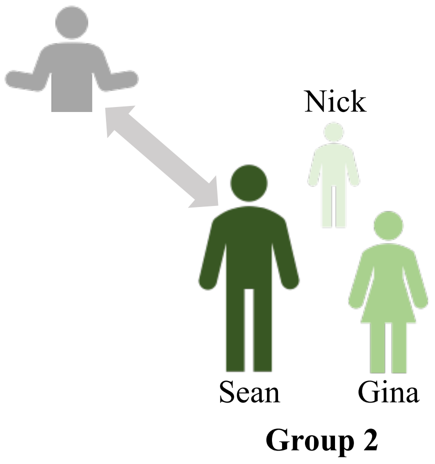


Figure 5.3: Group 2 dynamics, including relative size and color intensity for three students (green) illustrating their level of engagement. Gray arrows show directionality of engagement, such only Sean is substantively engaged in Constructive interactions with PLAs, as indicated by the double arrow.

When interacting with a PLA, Sean engaged in Constructive interactions by asking conceptual and procedural questions, describing his thought process, making self-corrections, and elaborating on the PLAs' statements. While more than half of Group 2's interactions were Constructive (55.3%), this group had the least Interactive interactions across the three groups (4.3%). This shows that their interactions with the PLAs were so dominated by Sean and specific to his individual thinking, that there may not have been space for his peers to participate. However, although more than half of their interactions were Low Quality, more than a third were Medium Quality. This suggests that Gina did make some contributions, but they were Active in nature as she asked questions or offered an idea, but they did not build on or relate to Sean's contributions. Moreover, because Nick made little contributions, but was listening to the interactions, his actions were considered Passive (Chi & Wylie, 2014).

The performance of students in Group 2 may have been mediated by the nature of their contributions to group discussion. Sean, the Constructive student, performed better than his groupmates, who engaged either Actively or Passively. This is supported by evidence showing that dialogue patterns in dyads are related to learning, such that the more Constructive partner (the speaker) learns more than the less Constructive partner (the listener) (Chi & Menekse, 2015). Interestingly, there was no considerable difference in Nick and Gina's performance, despite the discrepancy in their participation. Moreover, while Sean had higher performance than all students in Group 1, his performance was lower than most students in Group 5, which is consistent with other findings supporting the ICAP hierarchy, such that students in the Constructive mode learn more than those in the Active mode (Menekse et al., 2013), but learning is greatest in the Interactive mode (Menekse & Chi, 2019; Wiggins et al., 2017). My findings from Group 2 suggest that the student engaged in Constructive dialogue with a PLA may benefit in their performance, but this may not translate to other students in the group who are engaged Actively or Passively. However, it is possible that because the interactions were steered by Sean, more so than the PLAs, and relevant to his unique train of thought and questioning, this left little opportunities for his peers to participate. This may not have been the case if the PLAs had purposefully engaged Gina and Nick more in the discussions, rather than allowing Sean to dominate the interaction.

Group 5, which included Farrah, Peyton, and Jamie, was the most Interactive of the three groups, although most of their interactions were actually Active. Both Farrah and Peyton were frequent speakers in this group, but I considered Farrah to be the primary student because she seemed to lead most of their conversations. While both she and Peyton shared their thinking, Farrah was more insistent of her ideas than Peyton was. This often led to disagreements between Farrah and Peyton, which provided opportunities for them to question and challenge one another's ideas and make corrections in response. This was the only group that engaged in such evaluative behaviors, which was why they had more Interactive interactions than the other groups. I considered Jamie to be the tertiary student because she mostly listened to Farrah and Peyton's debates, and her contributions rarely offered new ideas (Figure 5.4).

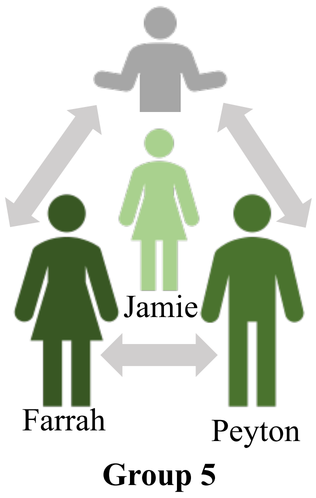


Figure 5.4: Group 5 dynamics, including relative size and color intensity for three students (green) illustrating their level of engagement. Gray arrows show directionality of engagement, such that Peyton and Farrah are engaged in Interactive interactions with PLAs and with each other, as indicated by the double arrow.

Overall, most of Group 5's interactions with PLAs were Active (46.9%). Often, Farrah asked the PLAs to confirm her thinking or problem-solving approach, which was a common characteristic of Active interactions. Interactive interactions were the second most observed interaction for this group (31.3%), and all of these were scored as High Quality, indicating that two or more students made substantial contributions to their collective sense-making dialogue. This was observed in the back-and-forth between Peyton and Farrah, as their ideas built on one another and they answered each other's questions, or they expressed disagreement and included the PLA to help correct their thinking. Both Peyton and Farrah were Constructively engaged, which made their interactions Interactive (Chi & Wylie, 2014).

The nature of Farrah and Peyton's dialogue explains why these two students had the highest performance of all students across groups, as the Constructive-Constructive dialogue pattern is the most enhancing for learning because partners contribute to each other's ideas (Chi & Menekse, 2015). Indeed, students that made elaborations on their peer's ideas showed higher learning gains than those who accepted their peer's ideas (Menekse & Chi, 2019). More specifically, Farrah and Peyton had higher performance than Sean in Group 2, despite the fact that he engaged in 24% more Constructive interactions than they engaged in Interactive interactions. While this pattern could be due to a number of reasons, it is supported by evidence showing that there is no significant difference in learning gains between students engaged in solo Constructive activities versus dyads with Low Constructive scores, but dyads with High Constructive (Interactive) scores perform significantly better than solo Constructive and Low Constructive dyads (Menekse & Chi, 2019). This demonstrates that learning is most supported when two or more students are Constructively engaged, thus making the interaction Interactive.

The majority of Group 5's interactions were Medium Quality (40.6%), and they had the most High Quality interactions across the three groups (31.3%). Notably, they also had zero No Quality interactions and only one Passive Interaction, indicating that this group was substantively engaged in the learning task (Chi & Wylie, 2014). This illustrates that Group 5 was highly Interactive, as at least two students made substantial contributions to more than 70% of their discussions. Menekse and Chi (2019) found that Interaction Quality Score was positively related to learning gains, which aligns with my findings that Group 5 performed better than Group 2 and Group 2 performed better than Group 1. Although Jamie, the tertiary student in Group 5, performed considered lower than her groupmates, her performance was the same or higher than five out of six students from Groups 1 and 2. Only Sean, who engaged in Constructive interactions with the PLAs, scored better than Jamie outside of her groupmates. This suggests Jamie may have benefitted from a lower level of engagement in Farrah and Peyton's dialogue even though she made fewer substantial contributions. Unlike the less engaged, lower performing students from Groups 1 and 2, (Gina, Nick, and Tori) Jamie was a participant in High Quality interactions. The learning gains between low performing students in a High Quality interaction and high performing students in a Low Quality interaction are not significantly different (Menekse & Chi, 2019), which may explain why Jamie benefitted from her group's interactions, as they were more Interactive than other groups.

In addition to my findings following the predicted ICAP hierarchy, such that the more Interactive a group was, the higher their performance, another hierarchal pattern exists. Layered on the ICAP framework is a students' level of participation in the PLA interaction itself. As described above, students did not participate in these interactions equally. Cobb and Yackel (1996) posited that participating in and contributing to the learning task constitutes the conditions for the possibility of learning, meaning that students cannot learn if they do not participate. This was evidenced here, as students who were more participatory, in that they made frequent, substantial contributions to the PLA interactions compared to their peers, performed better. Moreover, the more students participated and engaged Interactively in the PLA interactions, the higher their performance. Specifically, students that engaged in Interactive sense-making in the presence of the PLA had the highest performance, students that engaged in a Constructive dyad with the PLA had mid-level performance, and students that did not engage in substantive discussion with or in the presence of PLA had the lowest performance. A similar relationship was reported by Smith et al. (2011), who found that student learning gains were highest when peer discussion was followed by instructor feedback compared to peer discussion or instructor feedback alone, and this trend was consistent across low, medium, and high performing students. The observed pattern suggests a synergistic effect, such that substantially participating in collective sense-making during Interactive interactions with a PLA aids student performance.

This discussion of conclusions I present offers important implications for PLA pedagogy training and instructional decision-making to support student engagement in collaborative group work. I discuss these and the limitations of this study below.

5.2 Implications

Implications for PLA Pedagogy Training

When I started researching PLAs in undergraduate biology classes, I wanted to come away with a list of "best practices" for PLAs to effectively support student learning. While this study does not provide a full list, it offers insights on how PLAs can best facilitate generative interactions with students and encourage student participation in these interactions. These insights may be useful to incorporate into existing PLA pedagogy training courses or those currently under development for budding PLA programs.

Using the ICAP framework to explore PLA-student interactions, I found that most were characterized as Active. Because student learning is more supported in the generative modes of engagement (Chi & Wylie, 2014), it is important for PLAs to recognize the characteristics of an Active interaction so they can shift it towards a Constructive and Interactive one. For example, when a student initiates an interaction with a PLA to confirm their thinking or problem-solving approach, PLAs should not provide confirmation or a direct answer. Rather, PLAs should elicit student thinking or probe for reasoning by asking, “why do you think that?” or “can you explain your thought process to me?” even if the student’s thinking is accurate. Prompting student explanation is beneficial for student monitoring of their understanding, but students rarely do so without instructor encouragement (Repice et al., 2016). Furthermore, a key concept in PLA pedagogy training focuses on using formative assessment by asking questions to guide student thinking (Gray, 2013). However, short questions that elicit student recall of background information do not facilitate student knowledge building because they are not going beyond the material presented. To make the interaction Constructive, PLAs should ask open ended questions that require students to make an inference or apply their knowledge. That way, PLAs can assess what students understand about the concept, rather than what they can recall.

I found that Constructive interactions were the second most common type of PLA-student interaction across the three groups, but less than 15% were Interactive. Because the Interactive mode of engagement is the most supportive of student learning (Chi & Wylie, 2014), PLAs should make every effort to shift interactions this direction. In the Interactive mode, student ideas are coordinated and build off one another, meaning that students ask and respond to their peer’s questions, and elaborate on one another’s thinking to co-construct their understanding. PLAs can facilitate these types of interactions by deliberately prompting students to discuss their ideas with one another. This might look like a student responding to their peer's question, evaluate their peer's thinking, or expanding on their peer's idea. In these interactions, PLAs would use guiding and probing practices, rather than informing, to make student thinking visible. However, guiding questions should include higher-order cognitive skills, as these are more effective than lower-order skills, such as recall, in promoting co-construction of student ideas (Leupen et al., 2020). In doing so, they create opportunities for students to reflect on their thinking, identify confusion or disagreement, and work to resolve it (Repice et al., 2016). If students continue to direct their statements towards the PLA, the PLA could deflect to a peer and encourage them to engage in the discussion.

Similar to shifting interactions from Active or Constructive to Interactive, PLAs should be cognizant of tertiary students who showed limited participation in group discourse. In this study, the tertiary students made little substantial contributions, asked questions that focused on surface-level details rather than conceptual understanding, or infrequently spoke during PLA interactions. PLAs should be trained to be on the lookout for these students and intentionally bring them into the discussion. There must be sufficient turn-taking between group members for interactions to be considered Interactive, as this supports learners with more opportunities to ask questions and hear their peer's thinking (Menekse & Chi, 2019). Furthermore, tertiary students may become aware of an error in their own understanding when peers explain their thinking (Yackel et al., 1991). For this reason, PLAs should not only use practices that make student thinking visible, but be sure to engage all group members when doing so. In this way, each student in the group shares their thinking, allowing opportunities for students to make sense of their own understanding within the context of their peer's perspective. PLAs may recognize that tertiary students are reluctant to share their ideas or have trouble identifying what they don't understand. In these instances, the PLA could ask a group member to explain the concept before providing an alternative explanation themselves.

Several PLA programs from various universities have developed or improved on their pedagogy training courses using input from PLAs (e.g., Campbell et al., 2019; Purtell et al., 2020). To improve the PLA pedagogy training at this institution, I suggest that each of the three groups could be used as a case study that could be incorporated in the pedagogy course. A group of PLAs could re-enact elements of an Active, Constructive, or Interactive interaction, followed by discussion of how the PLA would navigate the interaction by identifying student behaviors congruent with the ICAP modes of engagement. For example, students engaged Actively might only be seeking for confirmation of their ideas without any follow up. PLAs could discuss solutions to each of these scenarios and reflect on similar situations they experienced while assisting students in the classroom. Similarly, case studies could be designed to help PLAs address issues in group dynamics, such as a dominant speaker or tertiary student.

Implications for Instructor Decision-making to Support Collaborative Learning

College science instructors that seek to transform their large, lecture-based courses into more student-centered learning spaces by incorporating active learning and collaborative group work may need additional instructional assistance. PLAs provide the support needed to implement such activities by adding more instructors in the class to answer student questions, and provide feedback. Moreover, having additional instructional support creates more opportunities to put student thinking at the forefront and engage students in scientific thinking. In this way, PLAs offer an approach to making traditional STEM courses more accessible and inclusive, a need that has been identified by STEM majors (PCAST, 2012). However, utilizing

PLAs effectively requires careful forethought and planning with respect to PLA preparation and instructional design decisions.

Evidence shows that students engaged in Peer Instruction (Mazur, 1997) become more expert-like in their thinking if working in permanent teams, as this promotes cohesive interactive engagement (Zhang et al., 2017). Therefore, in order to promote Interactive engagement with peer-assisted learning, instructors should consider making groups permanent for the duration of the semester. Moreover, Knight et al. (2015) found that groups containing four to five students interacting with PLAs may be more stimulating for the exchange of ideas compared to groups of two or three. Their finding aligned with a previous study which suggested that groups should be between three to five students to maximize participation and sharing of ideas (Beichner & Saul, 2003). Others have found that groups of three students show the highest performance in problem-solving tasks (Johnson et al., 2006). While students in this study were allowed to self-select into groups of three that remained stable for the duration of the semester, I did not find this group size to be beneficial for students. In my study, within the groups of three, there was one student who had limited engagement. It is possible that the PLA acted as a temporary group member, raising the group size to four, which may have inadvertently left the tertiary student out of productive dialogue. Given the range of findings regarding group size, it is likely context dependent and should be further investigated, but my findings suggest that students collaborating on an activity in a PLA-supported course may benefit from working in pairs.

PLAs programs, including the one at this institution, only require PLAs to complete the pedagogy training course in their first semester of working as a PLA. However, both first time and returning PLAs attend weekly content review meetings with the instructor of the course in which they are assisting. To adequately ensure that all PLAs are prepared to engage students in generative interactions and navigate issues related to group dynamics, instructors could use these weekly meetings to discuss these pedagogical practices in addition to content. That way, all PLAs have an opportunity to reflect on their approach to student interactions, even if they aren't enrolled in the pedagogy training course that incorporates the case studies described above.

5.3 Limitations

I conducted my research in a single course with one instructor, four PLAs, and three groups of three students. While this focused on a limited number of student groups, I recorded and analyzed over 100 PLA-student actions across the groups. This provided a rich understanding of what happening in the moment between PLAs and students. However, my findings may be institution and course dependent, such that instructors at other institutions may structure their courses differently (e.g., only using clicker questions rather than longer activities like open-ended worksheets) or utilize PLAs in a different manner. Furthermore, I did not consider the perspective of the PLAs in this study. Prior to this research, I interviewed PLAs at this institution to understand the strategies they described using to support student learning. While this earlier work informed my thinking in this study, I did not interview the PLAs involved in this research specifically. Additionally, I observed that certain PLAs were more successful in facilitating generative interactions than others, although I did not compare how these PLAs were better able to engage students in these types of discussions. Gaining the PLAs' perspectives about how they approached interactions with students may have produced a more nuanced understanding of how they responded to student needs and navigated group dynamics.

It is also possible that the conversation dominating students were able to be most engaged in their interactions with the PLAs because they had a better grasp of the material and thus, were more prepared to participate. Likewise, it is possible that the tertiary students were less participatory because they did not know the material, and therefore were unable to contribute to the interaction. I recognize that these are legitimate questions and that my research does not contain the data to answer them. However, the students in these groups had varying backgrounds in biology and I did not observe that their highest level of biology completed corresponded to their performance in this course. I acknowledge that students who were more comfortable with the content than their peers may have been more prepared to engage in discussion, but having listened to their discussions I believe the discomfort and confusion about the material was shared among group members. For these reasons, I contend that students who participated the most, both with peers and the PLA, performed better and likely achieved deeper learning than those who were less participatory in these interactions.

5.4 Future Research

The continuance of exploring PLA-student interactions in real-time to investigate *how* PLAs facilitate student learning is needed to elucidate the overwhelming evidence that students in PLA-supported courses perform better than those not supported by PLAs. This research provides an avenue to do so by offering my peer-led interactive discourse framework that other studies can apply to examine PLA-student interactions. This study appears to be the first that directly integrates the ICAP modes of engagement with PLAs. Future research might utilize my peer-led interactive discourse framework to consider how PLAs recognize different student modes of engagement and determine how to respond in order to ensure a generative interaction. As I mentioned, some PLAs were more successful at this than others, so interviewing PLAs about their approaches to student interactions or having them reflect on an interaction after listening to a recording of it, would help illuminate their efficacy. Moreover, a future study might examine the effectiveness of PLAs intervening in group dynamics to foster a more equitable discussion, and how tertiary students and conversation dominators respond to the PLA intervention. Lastly, it would be interesting to apply this framework in a different discipline that utilizes a more problem-based approach to learning, such as the physical sciences or engineering. As the life sciences are more conceptual, exploring how PLAs can productively engage students in interactions that focus on problem-solving would be beneficial across STEM fields.

5.5 Coda

I reflect on the questions that I've held about the efficacy of peer learning since I started as a peer tutor. Could it be "student speak?" Maybe, but that doesn't explain it all. Is it social constructivism? Somewhat, but other frameworks are more informative for our understanding. Are novice peer tutors really better than expert instructors? No, but they do help facilitate active learning opportunities and prompt students to participate in them. So, what now?

I know now that a PLA-supported classroom is rich with opportunities for student engagement. And I think I might know why, or at least how PLAs can be effective. PLAs create opportunities to put student thinking at the forefront of college classrooms. Although more and more instructors are incorporating active learning into their courses, additional instructional support is needed to ensure those activities are actually helping students build understanding. PLAs provide the instructional scaffolding to help students articulate their thinking and develop a conceptual understanding. Moreover, through peer-led interactive discourse, PLAs facilitate student learning by prompting students to engage with one another in a collective sense-making dialogue and support their discussion by guiding and probing student thinking. In this way, PLAs help students co-construct their understanding of course concepts, thereby supporting a deeper level of learning. At the heart of learning is participation, and PLAs are instrumental in cultivating student engagement to foster a student-centered learning community.

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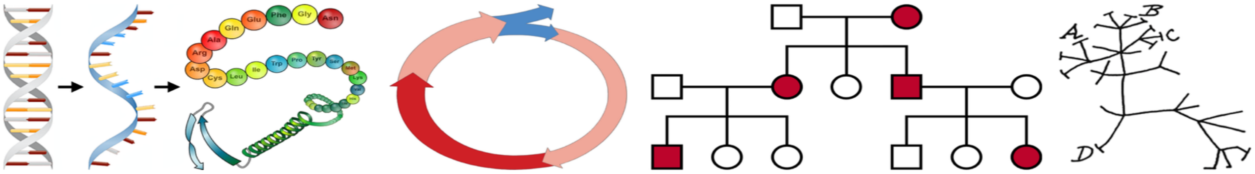
APPENDIX A

BIO 201 COURSE SYLLABUS

Principles of Biology Spring 2022



Enrollment: Participation in this course requires enrollment in the corequisite lab (BIO 201L), unless the lab has been completed. Although lecture and lab are linked, these two courses are independent. For enrollment questions, contact the biology advising office.

Course Materials: There is no textbook for this course, but instructional materials will be posted on eLC during the semester. If you are unable to access the website, contact the help desk. We will use the Top Hat response system during class, and you will need a device that connects to the Internet for participation. Licenses are $22 per semester for students, and you should receive an invitation with the join code for Top Hat by email during the first week of class.

Evaluation: Learning and course engagement will be evaluated by the assessments shown below.

Class Activities	Top Hat Questions and Practice Exams	100 points (25%)
Unit Exams 1-5	60 Points x 5	300 points (75%)

There are no dropped exams, and full credit is given for completing at least 90% of class activities.

Grades: You will receive a letter grade at the end of the semester according to the following scale, although thresholds for some or all letter grades can be decreased at the discretion of the instructor.

A	93% (92.50–100.0)	B–	80% (79.50–82.49)
A–	90% (89.50–92.49)	C+	77% (76.50–79.49)
B+	87% (86.50–89.49)	C	70% (69.50–76.49)
B	83% (82.50–86.49)	D	60% (59.50–69.49)

Academic Honesty: All work must be performed without receiving unauthorized assistance from another person, plagiarism, tampering, lying, stealing, or otherwise cheating. More information on academic honesty policies and consequences of violations can be found at https://honesty.uga.edu.

Violations on an exam will result in a score of zero. Smart devices such as phones and watches are not allowed during exams. Attempts to receive credit for class activities such as Top Hat questions and practice exams while not attending class will result in a score of zero for all affected activities.

Disabilities: Reasonable accommodations are available for students with documented disabilities when approved. For more information about disabilities or to apply for an accommodation, contact the Disability Resource Center. Inquiries are confidential.

Mental Wellness: Resources are available to help you manage difficult circumstances that happen in life, such as family emergencies and overwhelming anxiety. Contact Student Care and Outreach and counselors will help you navigate the situation.

Course Schedule

1/13	Introduction
1/18–2/1	Unit 1: Gene Expression
2/3	Unit Exam
2/8–2/22	Unit 2: Cell Division
2/24	Unit Exam
3/1–3/3	Unit 3: Reproduction
3/7–3/11	Spring Break
3/14–3/22	Unit 3: Reproduction
3/24	Unit Exam
3/29–4/12	Unit 4: Trait Inheritance
4/14	Unit Exam
4/19–5/3	Unit 5: Evolution
5/6	Unit Exam

Course Changes: This syllabus outlines the intended course structure, but changes are sometimes needed during the semester. All significant changes will be announced in class and posted on eLC.

APPENDIX B

UNI 204 SAMPLE SYLLABUS

Course Description

This Peer Learning Assistants training course will introduce participants to current research on how people learn, review strategies for engaging undergraduates in active learning, and offer opportunities to model effective group facilitation during session activities. Participants will participate in small group discussions of pedagogical resource materials, brainstorm solutions to common teaching challenges, and share personal reflections of their teaching experiences.

Course Materials

All required course content will be provided free of charge on eLC. You are welcome to print off materials for completing the assignments.

Learning Objectives

Upon successful completion of this course, Peer Learning Assistants will be able to:

- Integrate active-learning techniques into their teaching
- Teach learners with different levels of ability
- Employ effective questioning techniques
- Help students become self-directed learners
- Use different ways to assess and evaluate students

What We Will Cover Each Week

The schedule, policies, procedures, and assignments in this course are subject to change in the event of extenuating circumstances, by mutual agreement, and/or to ensure better student learning. All readings are required unless otherwise noted. Students should read/know the required material by the date listed, at which time we will discuss or use the scheduled readings in class.

Week	Course Schedule	
	Discussion Topic	**Reading/Viewing Material Due Before Class**
1	• Role of the Practitioner • Role Specific - Do’s and Don’ts • Conducting a Successful Session • Professional Ethics • Establishing Boundaries	• PLA Documents and Resources • *Teaching with Integrity*: Chap 9
2	• Activating Prior Knowledge	• *How Learning Works*: Chap 1

3	• How We Organize Knowledge	• *How Learning Works*: Chap 3
4	• Diversity and Inclusion • Intercultural Communication • Class and Privilege	
5	• Practical Applications- Bloom’s Taxonomy and Study Cycle	• *Teach Yourself How to Learn*: Chap 4
6	• Practical Applications- Metacognitive Learning Strategies • Advanced Study Skills	• *Teach Yourself How to Learn*: Chap 5
7	• Active Listening and Responding	• *How Learning Works*: Chap 5
8	• Giving Constructive Criticism	• *Creating Self-Regulated Learners*: Chap 2
9	• Test Taking: Retention Strategies	• *Teach Yourself How to Learn*: Chap 9
10	• University Health Center Resources	
11	• Fostering Self-Regulated Learning (reading, watching, and listening)	• *Creating Self-Regulated Learners*: Chap 3
12	• Semester Debrief	
13-14	• Working on Class Project	
15	• Final Group Presentations	

APPENDIX C

PLA CONSENT FORM

UNIVERSITY OF GEORGIA

CONSENT FORM

Peer Learning Assistants' Support of Student Learning in Introductory Biology

You are being asked to take part in a research study. The information in this form will help you decide if you want to be in the study. Please ask the researcher(s) below if there is anything that is not clear or if you need more information.

Principal Investigator:	**Co-Investigator 1:**
Dr. Julie Kittleson	Brittney Ferrari
Department of Math and Science Ed	Department of Math and Science Ed
jkittl@uga.edu	baferrari13@uga.edu

Co-Investigator 2:
[redacted]
Department of Plant Biology
[redacted]

The purpose of this study is to understand the ways in which Peer Learning Assistants (PLAs) support student learning in traditionally challenging courses and help students in these courses develop learning strategies. PLAs have been found to improve student success at UGA, but little is known about the strategies they use to help student and how students make use of the additional instructional support from PLAs.

This study seeks to understand how students' interactions with PLAs and their peers facilitate learning and sense making. To explore this, we will use audio recordings of student groups while they complete worksheet assignments together during class. All group assignments will be audio recorded throughout the semester to understand the nature of students' interactions with one another, and with the PLA. However, this will require no additional work on your part, you will not have to wear any type of recording device, and your name and identity will not be revealed.

If you AGREE to participate in the study, you will be asked to

- Respond to a short survey about your views on student learning and the role of PLAs. This should only take about 15-20 minutes to complete.

- Meet with assigned student groups, two of which will be audio recorded, regularly during class.
- Complete all PLA responsibilities normally associated with this course.

If you DO NOT AGREE to participate in the study

- You will still be expected to complete the normal responsibilities of a PLA during this class.
- Your interactions with student groups will not be audio recorded.

Your involvement in the study is voluntary. Your decision about whether or not to participate and allow your information to be used in this study will have no bearing on your position as a PLA.

Privacy/Confidentiality

All information containing information that can identify individual students that is collected for the study will be kept confidential on a secure computer in your instructor's office. All information will have identifying information (such as your name and 81#) removed and replaced with an anonymous code before being analyzed or shared with other researchers. The results of the research study may be published in summary form, but neither your name nor any other identifying information will be used. This research involves the transmission of data over the Internet. Every reasonable effort has been taken to ensure the effective use of available technology; however, confidentiality during online communication cannot be guaranteed.

Risks/Benefits

We do not anticipate any risks from participating in this research. There are no direct benefits for participating in this study. This study has the potential to improve the quality of future iterations of this course and of the Peer Learning Assistant Program at the University of Georgia.

Questions

Please feel free to ask questions at any time. You can contact Brittney Ferrari at baferrari13@uga.edu or [redacted] If you have any questions or concerns regarding your rights as a research participant in this study, you may contact the Institutional Review Board (IRB) Chairperson at 706.542.3199 or irb@uga.edu.

Please indicate whether you voluntarily consent to participate in research by selecting the appropriate option below.

☐ I ***AGREE*** to participate in this study.

☐ I ***DO NOT AGREE*** to participate in this study.

PLA ELIGIBILITY SURVEY

1. Please select the gender with which you identify:
    - Female
    - Male
    - Prefer to self describe as:
    - Prefer not to answer.

2. Please enter your full name.

3. With which race(s) and ethnicity/ies do you most closely identify? Please choose all that apply.
    - African American or Black
    - American Indian or Alaskan Native
    - Asian American
    - Asian Indian
    - Chinese
    - Japanese
    - Korean
    - Latina / Latino or Hispanic
    - Middle Eastern
    - Native Hawaiian or Other Pacific Islander
    - Vietnamese
    - White
    - Other:

4. How many semesters have you worked as a PLA?
    - This is my first semester as a PLA.
    - I have been a PLA for 1 semester.
    - I have been a PLA for 2 semesters.
    - I have been a PLA for 3+ semesters.

5. Please list the courses you have worked in as a PLA.

APPENDIX D

STUDENT CONSENT FORM

UNIVERSITY OF GEORGIA

CONSENT FORM

Peer Learning Assistants' Support of Student Learning in Introductory Biology

You are being asked to take part in a research study. The information in this form will help you decide if you want to be in the study. Please ask the researcher(s) below if there is anything that is not clear or if you need more information.

Principal Investigator:	**Co-Investigator 1:**
Dr. Julie Kittleson	Brittney Ferrari
Department of Math and Science Ed	Department of Math and Science Ed
jkittl@uga.edu	baferrari13@uga.edu

Co-Investigator 2:
[redacted]
Department of Plant Biology
[redacted]

The purpose of this study is to understand the ways in which Peer Learning Assistants (PLAs) support student learning in traditionally challenging courses and help students in these courses develop learning strategies. PLAs have been found to improve student success at UGA, but little is known about the strategies they use to help student and how students make use of the additional instructional support from PLAs.

If you AGREE to participate in the study, you will be asked to

- Complete all classwork normally associated with this course. This will include exams and worksheet assignments.
- Complete an online survey at the beginning and end of the semester that will ask about strategies and metacognitive awareness that should only take about 20 minutes.
- Share results of their unit and final exams with the researchers of the study. If you agree, this will be handled automatically and no action is required on your part.

If you DO NOT AGREE to participate in the study

- You will still be expected to complete the normal classwork and surveys associated with this course. However, your information will be removed from any collected data prior to analysis.
- Your unit and final exam results will not be shared with the researchers.

Your involvement in the study is voluntary. Your decision about whether or not to participate and allow your information to be used in this study will have no bearing on your grades or class standing.

Privacy/Confidentiality

All information containing information that can identify individual students that is collected for the study will be kept confidential on a secure computer in your instructor's office. All information will have identifying information (such as your name and 81#) removed and replaced with an anonymous code before being analyzed or shared with other researchers. The results of the research study may be published in summary form, but neither your name nor any other identifying information will be used. This research involves the transmission of data over the Internet. Every reasonable effort has been taken to ensure the effective use of available technology; however, confidentiality during online communication cannot be guaranteed.

Risks/Benefits

We do not anticipate any risks from participating in this research. An incentive is offered to students who complete the survey for this study, such that they will receive extra credit towards an exam in BIOL 1107. This study has the potential to improve the quality of future iterations of this course and of the Peer Learning Assistant Program at the University of Georgia.

Questions

Please feel free to ask questions at any time. You can contact Brittney Ferrari at baferrari13@uga.edu or [redacted] If you have any questions or concerns regarding your rights as a research participant in this study, you may contact the Institutional Review Board (IRB) Chairperson at 706.542.3199 or irb@uga.edu.

Please indicate whether you voluntarily consent to participate in research by selecting the appropriate option below.

☐ I ***AGREE*** to participate in this study.

☐ I ***DO NOT AGREE*** to participate in this study

CONSENT FORM (part 2)

This study also seeks to understand how students' interactions with PLAs and their peers facilitate learning and sense making. To explore this, we will be using audio recordings of student groups while they complete worksheet assignments together during class. All group assignments will be audio recorded throughout the semester to understand the nature of students' interactions with one another, and with the PLA. However, this will require no additional work on your part, you will not have to wear any type of recording device, and your name and identity will not be revealed.

If you AGREE to participate in the audio recordings, your professor will notify you of your group assignment.

If you do NOT AGREE to participate in the audio recordings, you can still participate in the other component of this study.

☐ I ***AGREE*** to participate in part 2 of this study.

☐ I ***DO NOT AGREE*** to participate in part 2 of this study.

STUDENT ELIGIBILITY SURVEY

1. Please select the gender with which you identify:
    - ○ Female
    - ○ Male
    - ○ Prefer to self describe as:
    - ○ Prefer not to answer.

2. Please enter your full name.

3. With which race(s) and ethnicity/ies do you most closely identify? Please choose all that apply.
    - ○ African American or Black
    - ○ American Indian or Alaskan Native
    - ○ Asian American
    - ○ Asian Indian
    - ○ Chinese
    - ○ Japanese
    - ○ Korean
    - ○ Latina / Latino or Hispanic
    - ○ Middle Eastern
    - ○ Native Hawaiian or Other Pacific Islander
    - ○ Vietnamese
    - ○ White
    - ○ Other:

4. What is your year of study?
    - ○ 1st year
    - ○ 2nd year
    - ○ 3rd year
    - ○ 4th year
    - ○ 5th year or higher

5. Is this your first time taking BIOL 1107 or equivalent?
    - ○ Yes
    - ○ No

6. Have you taken a course that utilized PLAs at this university before?
    - ○ Yes
    - ○ No

7. What is your major?

8. What is the highest Biology course that you have completed with a passing grade?
    - College biology course for science majors
    - College biology course for non-science majors
    - Advanced placement biology
    - Biology course in high school
    - No biology course completed